# 7056 ENG

Resource Planning and Management

School of Engineering

# Topics

Topic 1 **Introduction to Planning**

Topic 2 **Network Analysis**

Topic 3 **Resource Planning with Networks**

Topic 4 **Non-Network Resource Planning**

Topic 5 **Crashing Networks**

Topic 6 **Queuing Theory and Simulation**

Topic 7 **Decision Making Tools**

Topic 8 **Cost Planning**

Topic 9 **Inventory Management**

This unit has been produced as study materials for *7056ENG Resource Planning and Management*, which is one of the units offered by the School of Engineering in Griffith University's Master of Engineering Program.

The unit has been prepared by Dr Rodney Stewart, Lecturer in Construction Engineering and Management.

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# 7056ENG

Resource Planning and Management

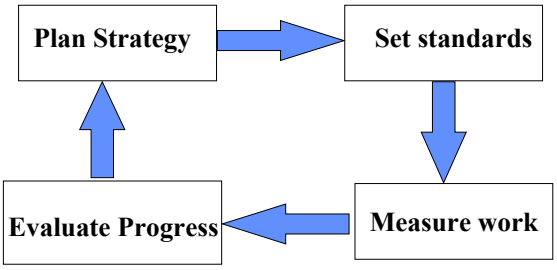
# LECTURE NOTES

Dr Rodney Stewart

# Introduction

Dr Rodney Stewart

## THE PROJECT CONTROL CYCLE




## Project Planning Methodology

- **Project objectives and requirements are set**
- **Consider restraints, opportunities and options**
- **Specific work activities are defined and listed**
- **Project organisation is created**
- **A schedule is prepared**
- **A budget/resource plan is prepared**
- **A forecast is prepared of time, cost, etc.**
- **Monitor progress**
- **Review the model**
- **Take action**

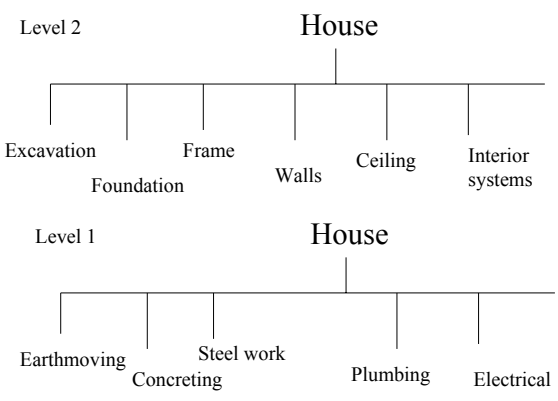
Who Plans?
Levels of Planning
Characteristics of a Good Plan

## Contents of Project Summary Plan

- **Introduction**
- **Management summary**
- **Management and organisation section**
- **Technical Section**

## TOOLS OF PROJECT PLANNING

- **Work Breakdown Structure (WBS)**
- **Responsibility Matrix**
- **Events and Milestones**
- **Logic Work Lists, Bar Charts and Networks**
- **Cost Estimating and Budgeting**



## WORK PACKAGES

**A typical work package description includes:**

- A summary of the work to be accomplished
- Inputs required from other project tasks
- The manager/organisational unit responsible
- Product specifications
- Resource estimates
- Total cost and budget
- Scheduled dates and milestones events

## ACTIVITY-ON-ARROW DIAGRAMS

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## Network Diagram

**A diagrammatic representation of a program or plan for a project that shows the correct sequence and relationship of activities and events required to achieve a given objective.**

**Characteristics:**

- **Shows the logic of the project**
- **Each arrow represents an event necessary to complete the project**
- **A dummy activity is used to indicate a required dependency**

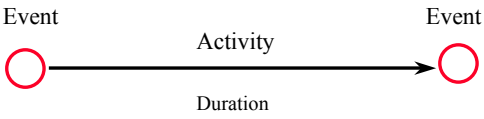
# ACTIVITY-ON-ARROW DIAGRAMS

**Arrow Diagram Definition**

**each activity is *uniquely* identified by event numbers**

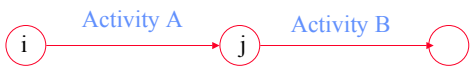
**The logical sequence between activities is represented by linking activities at their starting or ending nodes**

# I-J Network Symbols




**Terminology:**

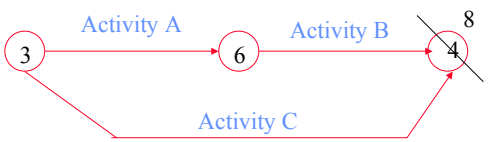
| | |
|---|---|
| **Node** | **Arrow** |
| **Preceding** | **Succeeding** |
| **Forward Pass** | **Backward Pass** |
| **Float** | **Critical** |

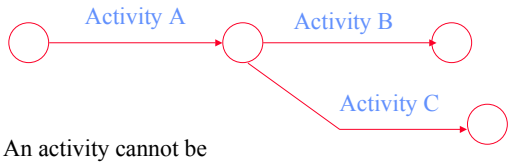



SEQUENCE & DEPENDENCY

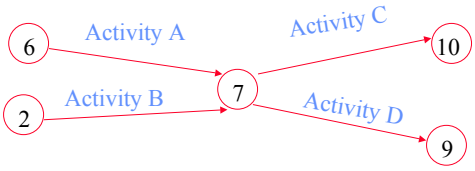
A ***precedes*** B while B ***follows*** A

Numbering System flow with the logic direction



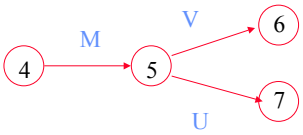


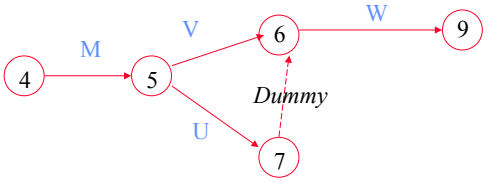

An activity cannot be interrupted




**Dummy activities**

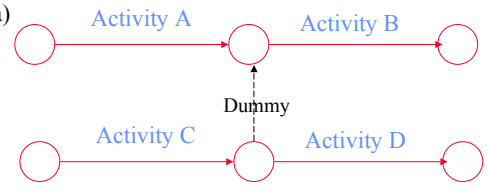
| Activity | IPA |
|---|---|
| V | M |
| U | M |
| W | V+U |



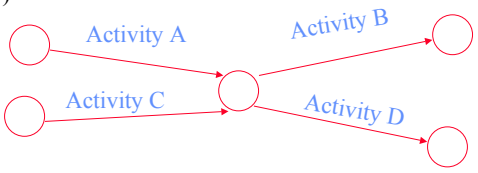




**To preserve the unique description for each activity**

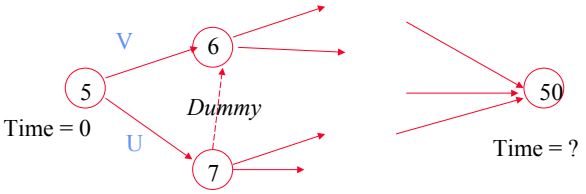
(a)



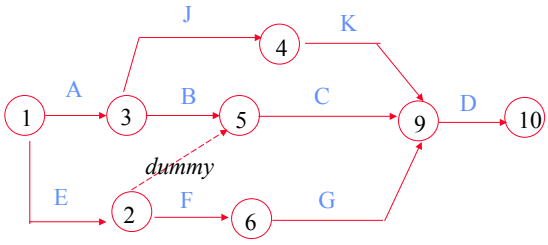

(b)



**Single Start and End Events**




| ID | A | E | J | F | K | C | G | D | B |
|---|---|---|---|---|---|---|---|---|---|
| IPA | -- | -- | A | E | J | B&E | F | C,K&G | A |

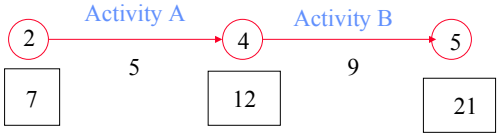


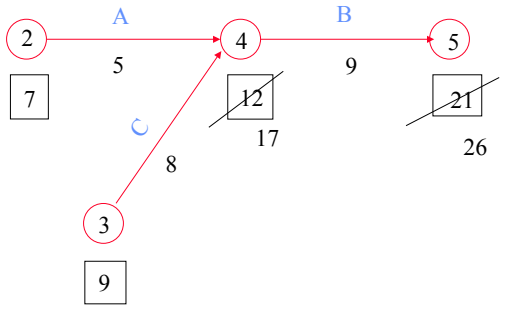

**ACTIVITY-ON-ARROW DIAGRAM**

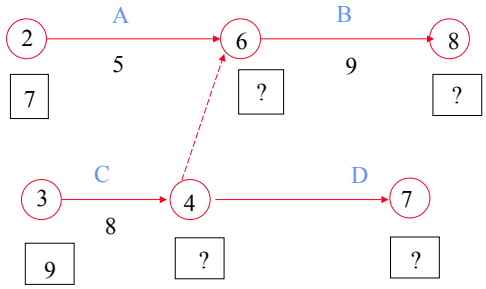
# TIME ANALYSIS

**What is the earliest that an event may occur?**

**Forward Pass:** ***Adding activity duration to the Early Event Time*** **EFi at the start of the activity**



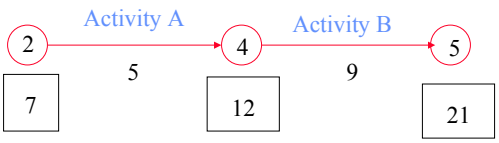


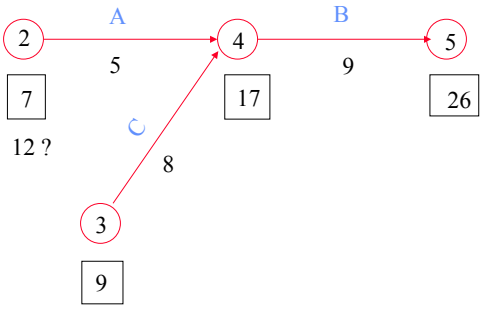



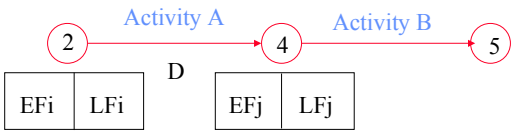

**What is the latest that an event may occur?**

**Backward Pass:** ***Subtracting activity duration from the Early Event Time*** **EFi at the start of the activity**

**Moving from the project's end to its start**



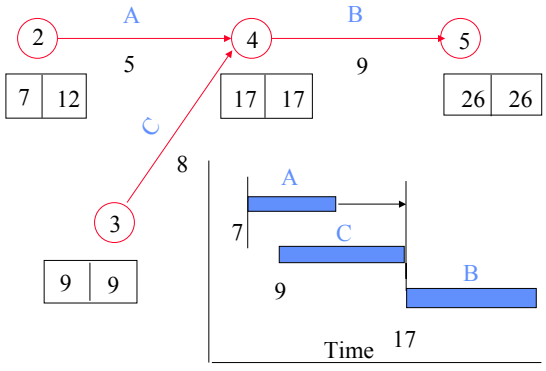



**For the activity:**

**ES = EFi** **LF = LFj**
**LS = LF - D** **EF = ES + D**

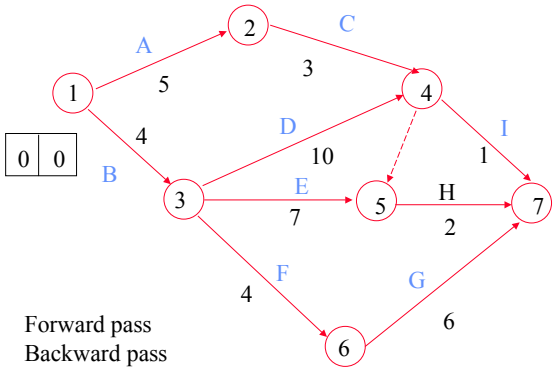
# FLOAT CALCULATIONS

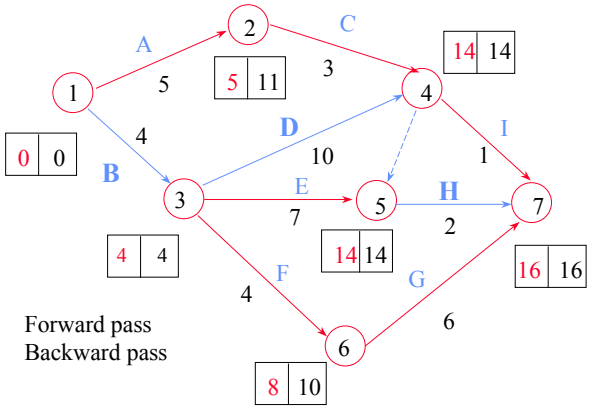


**Total Float (TF):**
**is the spare time by which the start of an activity may be delayed without *causing the project to last longer*.**

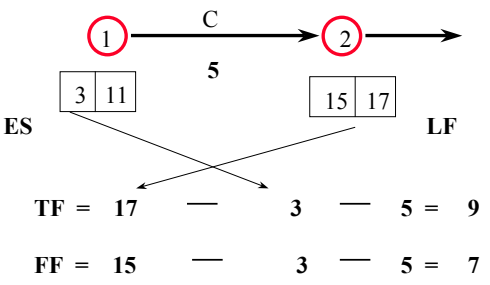
**Free Float (FF):**
**is a part of TF representing the spare time which can be used in delaying the activity without *affecting the start time of any successors.***

**TF = LF - EF = LFj - EFi - D**
**FF = EFj - EFi - D**

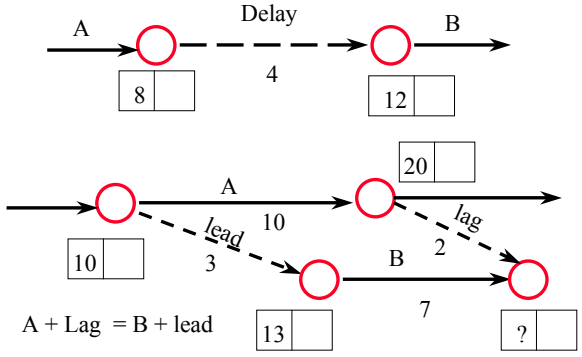


## Rules for Calculating Float




## Delay, Lead (delay start) and Lag (delay finish)




# ACTIVITY-ON-ARROW DIAGRAMS

# PDM NETWORKS

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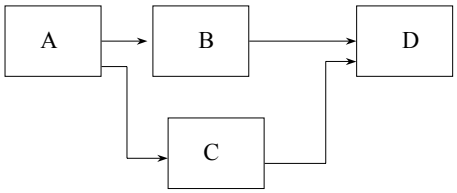
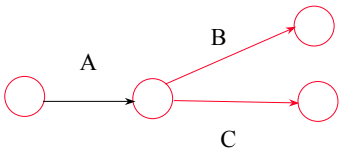
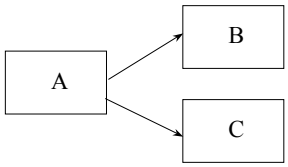
# Precedence Diagram Method (PDM)
# Activity-on-Node Network




**A method of network programming in which the activities are shown in the node box and connected by lines to show their inter-relationship**



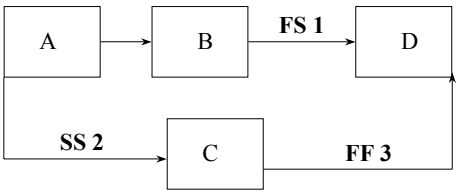

**Activity-on-arrow**




**Activity-on-node**

**Characteristics:**

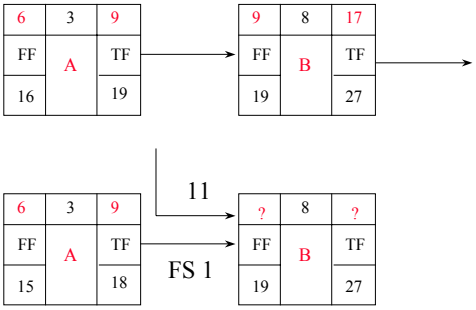
- **Shows the logic of the project**
- **Each node represents an activity necessary to complete the project**
- **No dummy activities are necessary**



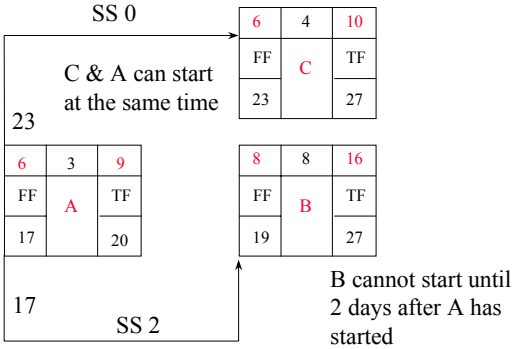
| ES | D | EF |
|---|---|---|
| FF | ID | TF |
| LS | | LF |

SINGLE ACTIVITY

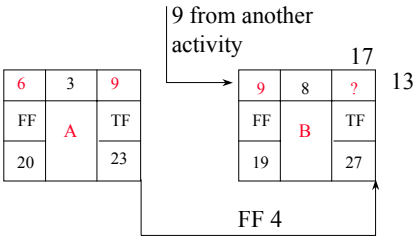
## Finish to Start Relationship




## Start to Start Relationship

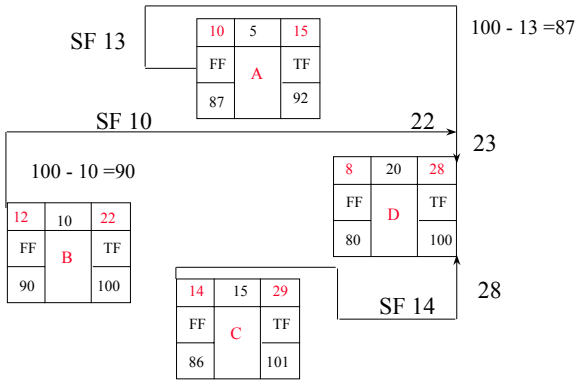


# Finish to Finish Relationship

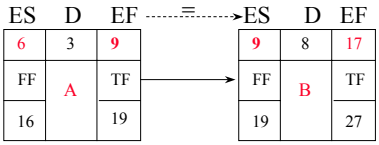



B cannot finish until 4 days after A has finished

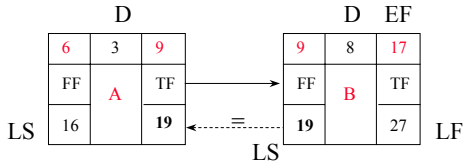
# Start to Finish Relationship



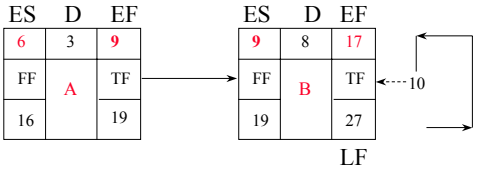

# Forward Pass



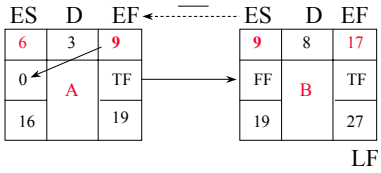

# Backward Pass



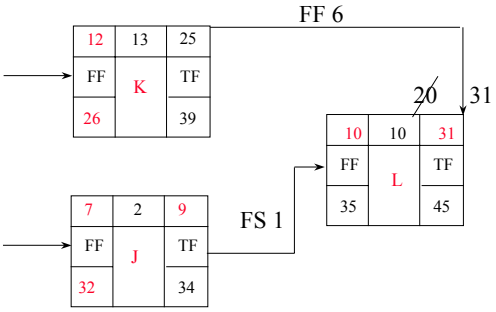
## Total Float

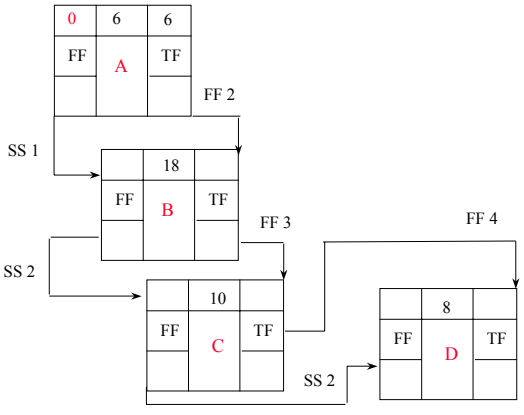


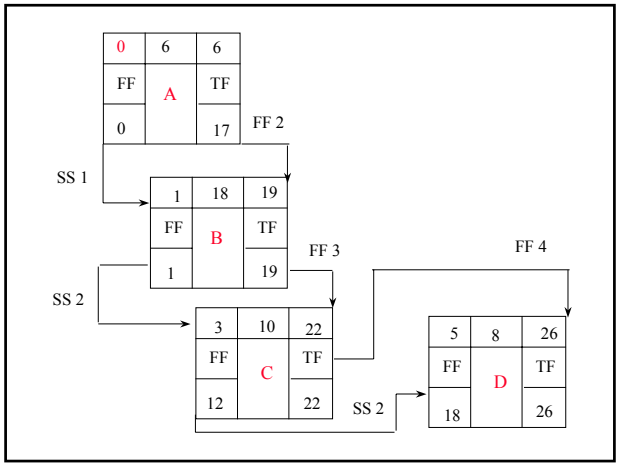

## Free Float




## Several Dependencies At A Node




0
6
6
FF
A
TF
0
17
FF 2
SS 1
1
18
19
FF
B
TF
1
19
FF 3
FF 4
SS 2
3
10
22
FF
C
TF
12
22
SS 2
5
8
26
FF
D
TF
18
26

# PERT NETWORKS

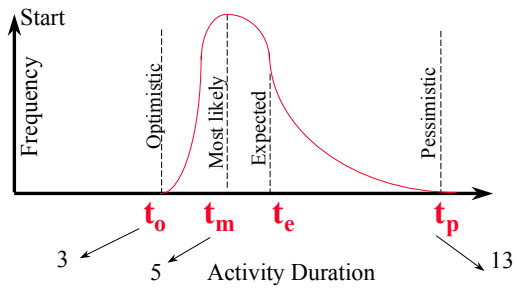
Dr Rodney Stewart

## PERT NETWORKS

Why do we need PERT?
Deterministic vs. Probabilistic duration
Variability in estimating duration or
Probability of meeting the target

PERT allows for
- **Optimistic**
- **Most likely and**
- **Pessimistic values**

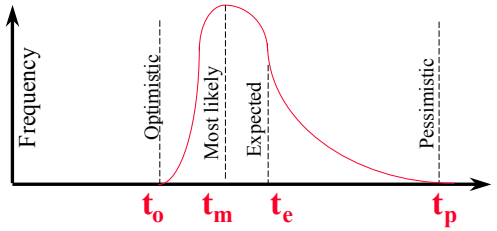
**to be considered in predicting the overall time**




**Continuous Probability Distribution**

**Expected time**

$$t_e = [\, t_o + 4t_m + t_p \,] \;/\; 6$$




Statistically speaking, the distance from one end of this distribution to the other end is **6 standards deviations** ($\pm 3S$)

$$S = (t_p - t_o) / 6$$

| Activity | $t_o$ | $t_m$ | $t_p$ | $t_e$ | s | v |
|---|---|---|---|---|---|---|
| 0-1 | 5 | 8 | 13 | 8.33 | 1.33 | 1.78 |
| 1-2 | 3 | 5 | 10 | 5.50 | 1.16 | 1.36 |
| 2-5 | 12 | 20 | 22 | 19 | 1.67 | 2.78 |

**Why do we need to know about V** (measure of variability)?

To measure the uncertainty of our estimation.

The larger **V**, the less reliable **te**, and the higher the likelihood that the activity will be completed much earlier or much later than **te**.

Since **Te** is computed as the sum of average times, **Te** itself can be thought of as an average time.

This means that there is a 50% chance that the project will be completed in less than **Te** and a 50% chance that it will exceed **Te**.

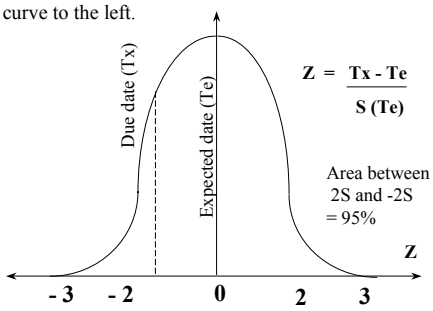
$$V(Te) = \Sigma V$$

The variation of the distribution of **Te** is computed as the sum of all C.P. variances.

In other words, use the variance of critical activities to assess the variance of the overall project.

In our analysis, we will assume that the project completion date (**Te**) follows the familiar normal probability distribution

To determine what is the probability of meeting a proposed deadline, it is necessary to determine the area under the normal curve to the left.




Z is the number of standard deviations the due date lies beyond the expected date

| Activity | $t_o$ | $t_m$ | $t_p$ | $t_e$ | s | v | |
|---|---|---|---|---|---|---|---|
| 0-1 | 5 | 8 | 13 | 8.33 | 1.33 | 1.78 | |
| 1-2 | 3 | 5 | 10 | 5.50 | 1.16 | 1.36 | Critical |
| 2-5 | 12 | 20 | 22 | 19 | 1.67 | 2.78 | Critical |

Te = 41.8 weeks

V (Te) = Σ V = 6.86

S (Te) = 2.62

So if my target is 43 weeks

$$Z = \frac{Tx - Te}{S(Te)} = \frac{43 - 41.8}{2.62} = 0.458 \longrightarrow 67\%$$

## Steps for PERT

1. Estimate to, tm, tp for each activity (given values)
2. Compute te for each activity (use te equation)
3. Calculate standard deviation for each activity

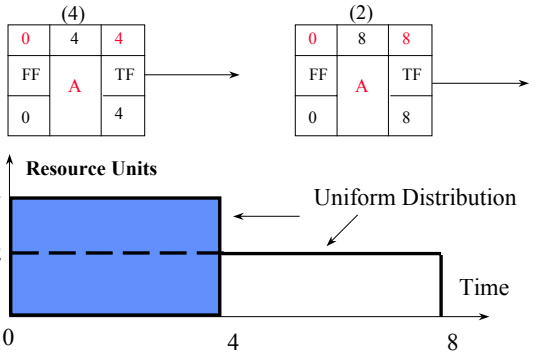
   S = ( tp - to ) / 6
4. Calculate variance for each activity

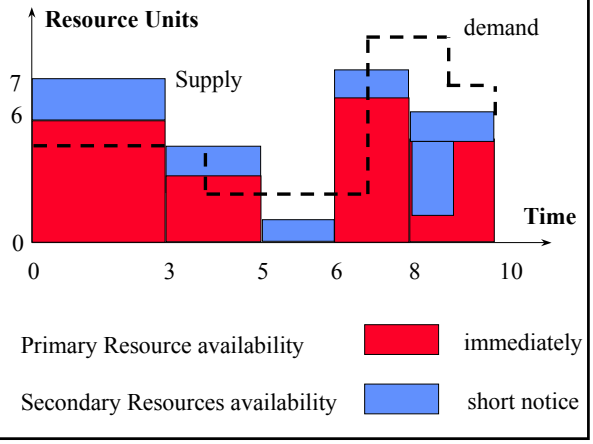
   V = S*S
5. Determine ES, EF, LS, LF, TF, FF
6. Determine Te (Critical Path) = Σ te along C.P.
7. What is the confidence in calculated Te

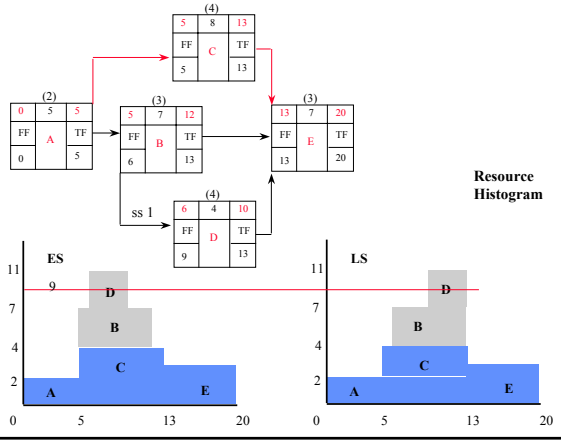
   V (te) = Σ V for ***critical activities only***

   and project standard deviation S (te) = $\sqrt{V(te)}$
8. Use probability tables to compute your chance in meeting the target duration

# RESOURCE HANDLING



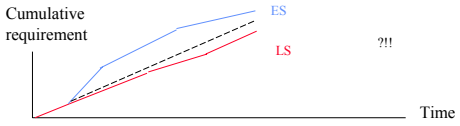



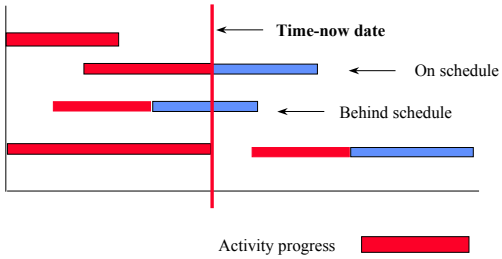
In practice, there might be **too many** options.
It all depends on your perspective and priorities.
Once you compared supply to demand, investigate ways of levelling/smoothing the demand profile

- Use of free float on activities demanding that resource
- Use of total float
- Use of flexible resources to stretch activity duration
- Extend the project total time (last resort, if no penalty is involved)

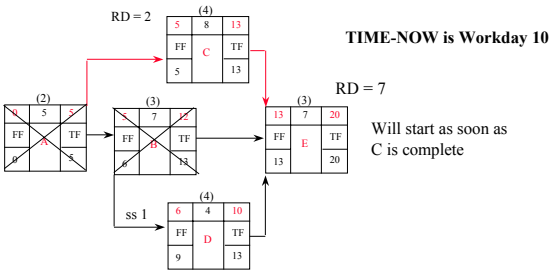
The ideal histogram is that with as few changes in level as possible
Remove the *peaks* and Raise the *valleys*




## MONITORING USING BAR CHARTS

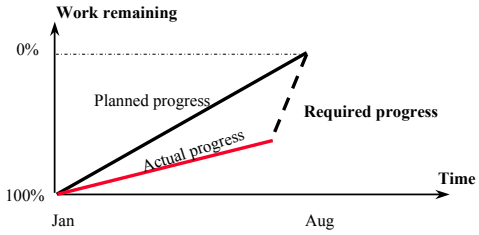



## MONITORING USING NETWORKS




RD = remaining duration

## MONITORING USING KEY TRENDS




- Identify critical and near critical activities
- Identify milestone dates for completion on a percentage basis %50, %60%, ...
- Monitoring to be undertaken on a regular basis
- Decisions to be made by management to bring the project back in line with the program.

## CRASHING NETWORKS

**Reducing the projected completion date by evaluating the plan and re-scheduling it with network logic or resource allocation changes**

***To crash (compress) a network*:**

**HIGHLIGHT CRITICAL ACTIVITIES**

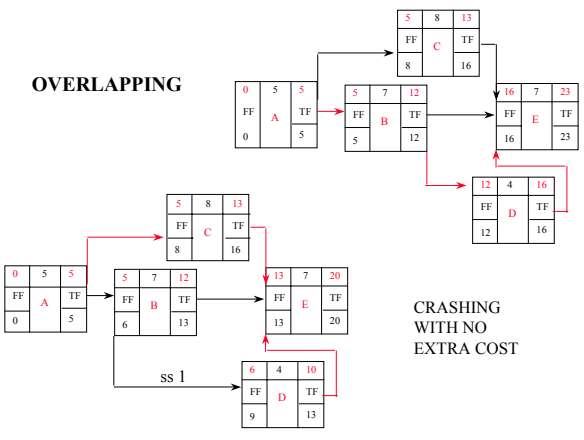
**CHECK LOGIC (Multiple-Dependency, Overlap, Lead times)**

**REVIEW DURATION (Significant Activities)**

**REVIEW TECHNIQUES (Construction Methods) COST!!!**

**MAKE CHANGES** **CHECK NEW CRITICAL PATH**

**OVERLAPPING**



# CRASHING NETWORKS

Dr Rodney Stewart

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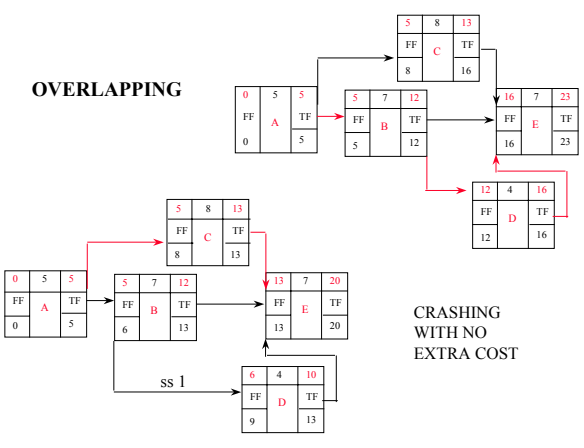
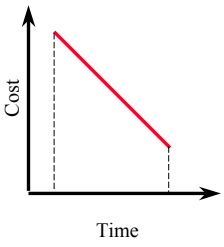
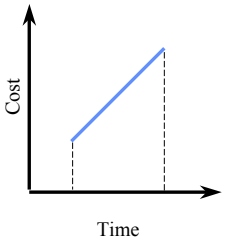


## CRASHING NETWORKS AT EXTRA COST

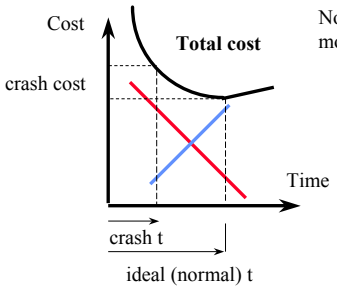
This technique is used after attempts have been made to crash the network at no extra cost.




Direct costs of project




Indirect costs of project



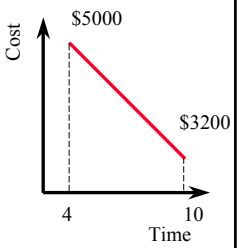

Normal point:
most efficient for least cost

Total project costs = Direct + Indirect costs

**The objective of each stage in crashing a schedule is to work on *one* (or more) activities to produce a feasible *shorter schedule* for the *minimum increased direct cost per unit*.**

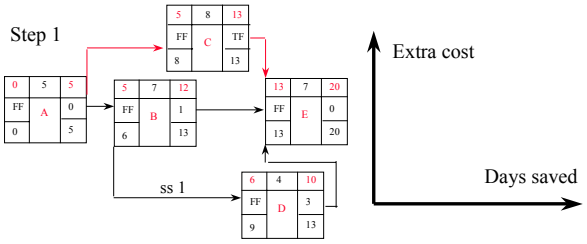
Steps:

1. List all activities on the critical path
2. Select the activity with potential
   (time savings for least cost: low slope)
3. Determine new critical path(s) if any
4. Re-evaluate the network
5. Repeat the above for another activity.



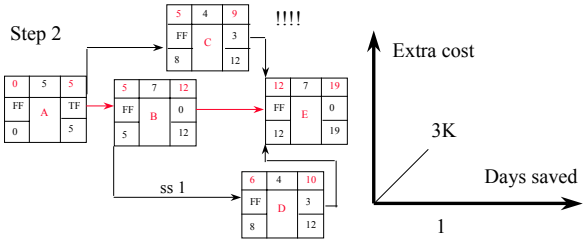

cost slope= $300/day

Step 1




| Activity | Normal cost | Normal time | Crashed cost | Crashed time | Extra cost | Saved time |
|---|---|---|---|---|---|---|
| A | $10,000 | 5 days | n/a | n/a | n/a | n/a |
| B | $15,000 | 7 | $20,000 | 5 days | $5,000 | 2 days |
| C | $27,000 | 8 | 30,000 | 4 | 3,000 | 4 days |
| D | $ 8,000 | 4 | 9,000 | 3 | 1,000 | 1 day |
| E | $10,000 | 7 | 20,000 | 4 | 10,000 | 3 days |

Step 2




| Activity | Normal cost | Normal time | Crashed cost | Crashed time | Extra cost | Saved time |
|---|---|---|---|---|---|---|
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| D | $ 8,000 | 4 | 9,000 | 3 | 1,000 | 1 day |
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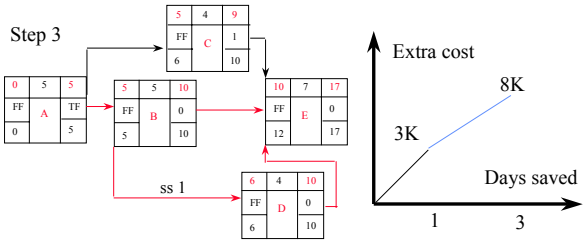
Step 3




| Activity | Normal cost | Normal time | Crashed cost | Crashed time | Extra cost | Saved time |
|---|---|---|---|---|---|---|
| *A* | *$10,000* | *5 days* | *n/a* | *n/a* | *n/a* | *n/a* |
| *B* | *$15,000* | *7* | *$20,000* | *5 days* | *$5,000* | *2 days* |
| *C* | *$27,000* | *8* | *30,000* | *4* | *3,000* | *4 days* |
| D | $ 8,000 | 4 | 9,000 | 3 | 1,000 | 1 day |
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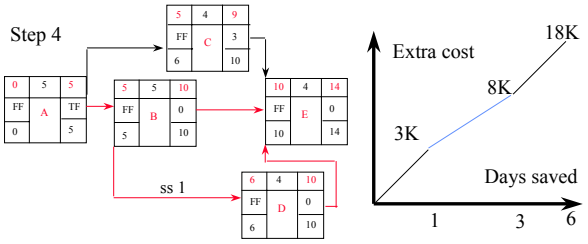
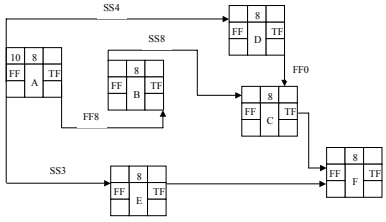



| Activity | Normal cost | Normal time | Crashed cost | Crashed time | Extra cost | Saved time |
|---|---|---|---|---|---|---|
| *A* | *$10,000* | *5 days* | *n/a* | *n/a* | *n/a* | *n/a* |
| *B* | *$15,000* | *7* | *$20,000* | *5 days* | *$5,000* | *2 days* |
| *C* | *$27,000* | *8* | *30,000* | *4* | *3,000* | *4 days* |
| D | $ 8,000 | 4 | 9,000 | 3 | 1,000 | 1 day |
| *E* | *$10,000* | *7* | *20,000* | *4* | *10,000* | *3 days* |

**EXAMPLE:**

**CRASHING NETWORKS**



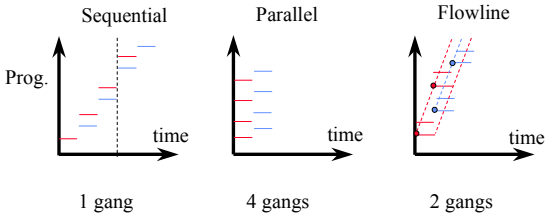

a) Fully analyse the PDM detailed above and show the critical path? What is the total completion time for the project?

b) The project manager requests that you crash the above network. Based on the following information, which option would you choose to start crashing the network? And why?

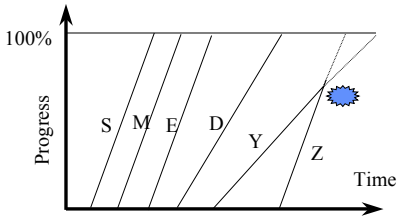
| Activity | Normal Duration | Crashed Duration | Extra Cost ($) |
|---|---|---|---|
| A | 8 | 6 | $10,000 |
| B | 8 | 6 | $4,000 |
| C | 8 | 4 | $32,000 |

## Non-Network Resource Planning Techniques

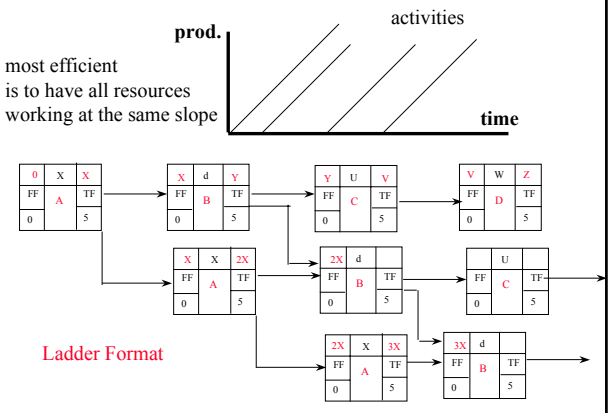
3 Types of Schedules Possible




Goal : a combination to optimise resources




As long as the slopes are either equal or decreasing as one moves to the right, the project should proceed satisfactorily. However, if scheduling shows one operation proceeding too rapidly, with a high slope compared with those preceding it, conflict occurs.




# LINE OF BALANCE (LOB)

LOB is a graphic technique used to :

- Plan the production of repetitive operations.
- Examine the implications of using given resource configurations for such operations.

**Applications:**

Repetitive construction work (over and over) (multi-storey building, pipelines, road construction)

**Conditions:**

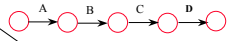
Direct control on repetitive activities

**Aim:**

Provide regular/balanced delivery of the product based upon continuous use of resources.

The first step is to **prepare your logic diagram**
then, **estimate the resource units** (eg manhours) to complete each activity. Using the above, **determine actual production rate**

Construct: **106 units** (Walker, p. 117)
5 working days@ 7hr/day = **35hrs/week**
Target Rate R = **8 units per week**



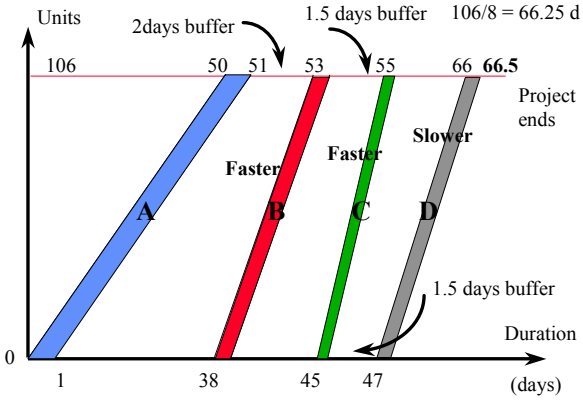

| Act. ID | Manhours req'd | Gang size | Theoretical gang size for Rate R | Actual gang size | Actual rate of output (units/week) |
|---|---|---|---|---|---|
| A | 20 | 3 | 8*20/35 = 4.6 | 6 | (6/4.6)*8 =10.5 |
| B | 2 | 2 | 8*2/35 =0.46 | 2 | (2/0.46)*8 = 35 |
| C | 2 | 3 | 8*2/35 =0.46 | 3 | (3/0.46)*8 = 52.5 |
| D | 5 | 4 | 8*5/35 =1.14 | 4 | (4/1.14)*8 = 28 |

The second step is to **determine time required to complete 1 unit** and the elapse time per activity (the start of last unit - the start of 1st)
Using these values, **represent each activity graphically**

Manhours required
Theoretical gang size

| Act. ID | Actual rate of output (units/week) | Time per activity (days) | Elapsed time bet. start on 1st unit and last unit (days) |
|---|---|---|---|
| A | 10.5 | 20/(3*7) = 0.95 | (105*5)/10.5 = 50 |
| B | 35 | 2/(2*7) = 0.14 | (105*5)/35 = 15 |
| C | 52.5 | 2/(3*7) = 0.10 | (105*5)/52.5 = 10 |
| D | 28 | 5/(4*7) = 0.18 | (105*5)/28 = 19 |

7 hrs per day
round them off to multiple 0.5 days
5 days per wk
(106-1)



The buffer is to allow for any delays/problems that may occur during the contract period.
This buffer time is the ***minimum time*** for ***all delays*** between activities to ***all units***.

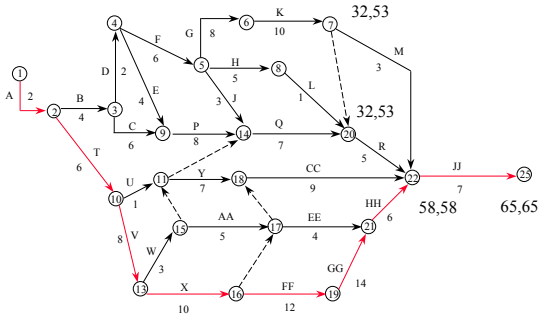
**The LOB technique is based on:**

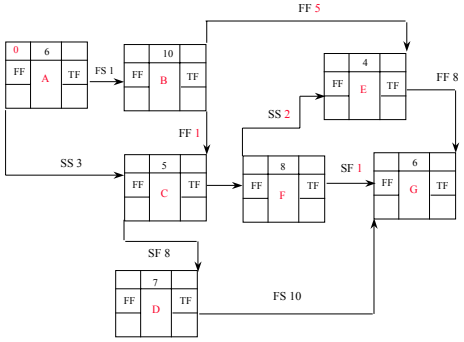
- repetitive operations
- continuity for each activity's workforce
- regular delivery of units to the client

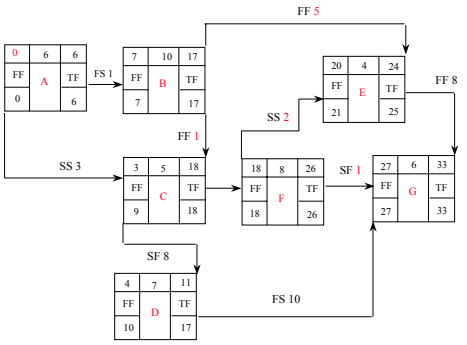
# QUEUING THEORY

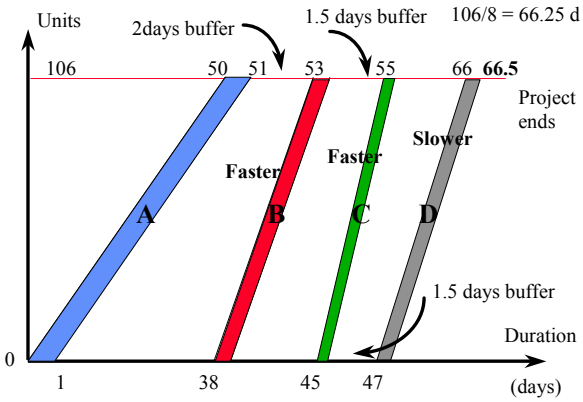
# SIMULATION

Dr Rodney Stewart






# WORK STUDY

**Systematic examination of any job so that the most effective and economical use of resources can be obtained.**

**Work measurement**

**determines basic output rates**

**more effective use of resources**

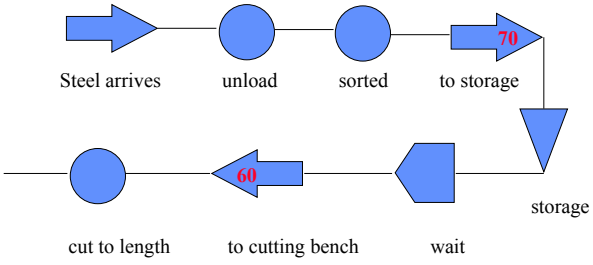
**Method study**

**improves production methods**

**improves planning and control rates for incentive payments**

| Step Description | Quantity | Distance | Time | Operation | Inspection | Transport | Storage | Delay | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Steel delivered | | | | | | → | | | by road |
| Unload | | | 75 | ● | | | | | mobile crane |
| Sorted | | | 20 | ● | | | | | by hand |
| To storage | | 70 | | | | → | | | mobile crane |
| Storage | | | | | | | ▼ | | |
| Await delivery to cutting bench | | | | | | | | ▶ | |
| To cutting bench | | 60 | | | | → | | | |
| Cut to length | | 90 | | ● | | | | | 3 workers |

**A FLOW PROCESS CHART**




**A FLOW DIAGRAM**

## **Problem**:

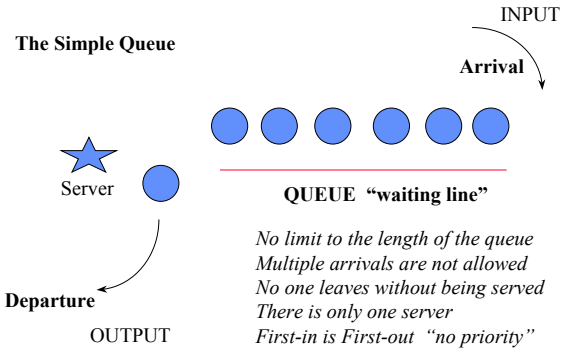
Material arrives at the average rate of five (5) loads per hour. The material is handled by a fork-lift truck which has an average rate of seven (7) loads per hour.

**Management requires to know:**

a) the average number of loads at the section waiting to be moved, when there is a queue
b) the average length of time an arriving load spends waiting for service
c) what the average service-rate must be in order to reduce the expected waiting time to 15 minutes for a load.

# QUEUING THEORY

**The Simple Queue**

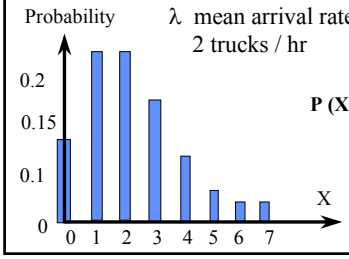



*No limit to the length of the queue*
*Multiple arrivals are not allowed*
*No one leaves without being served*
*There is only one server*
*First-in is First-out "no priority"*

## Pattern of Arrival

**Random "independent of one another"**

**The number of arrivals per unit of time can be estimated by a probability distribution "Poisson distribution"**



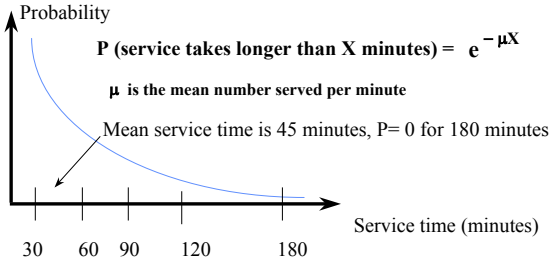

λ mean arrival rate **X no. of trucks/hr**
2 trucks / hr

$$P(X) = \frac{e^{-\lambda} \lambda^{X}}{X!}$$

The probability of 0 trucks arriving in any random hour is about 13%

## Pattern of Service

**The random service times can be described the -ve exponential probability distribution**



# QUEUING EQUATIONS

$\lambda$ mean arrival rate
$\mu$ mean rate of service $\mu > \lambda$

The Traffic Intensity $\rho = \lambda / \mu$

**Equations:**

The number of units in the system; $N = \dfrac{\lambda}{\mu - \lambda}$ **(1)**

2 trucks arriving per hr
3 trucks serviced per hr

then N = 2/(3-2) = 2 trucks in the system on the average

The average time a unit spends in the system; $T = 1 / (\mu - \lambda)$ **(2)**

T = 1 (3-2) = 1 hr

The average number of units in the queue; $Nq = \dfrac{\lambda^2}{\mu(\mu - \lambda)}$ **(3)**

Nq = 2*2 / 3(3-2) = 1.33 trucks on average

The average time a units spends in the queue $Tq = \dfrac{\lambda}{\mu(\mu - \lambda)}$ **(4)**

Tq = 2/ 3(3-2) = 40 minutes

The utilisation factor $\rho = \lambda / \mu$ 67% of time server is busy

Probability of having no trucks in the system = 33%

Probability of more than N trucks in the system

$P = (\lambda / \mu)^{N+1}$ where N = 0, 1, 2, 3, ...

| N | P |
|---|---|
| 0 | 0.667 |
| 1 | 0.444 |
| 2 | 0.296 |
| 3 | 0.198 |
| 4 | 0.132 |
| 5 | 0.088 |
| 6 | 0.058 |

Since on average a truck has 40 minutes wait, if the service centre works 8 hrs/day, the total number of hours that drivers spend waiting for servicing each day is

40 * 8 * 2 = more than 10 hours

For a simple queue, what is the average number of customers in the system for a traffic intensity of 0.5, 0.8, 0.9 and 0.95?

$\rho = \lambda / \mu$

$N = \frac{\lambda}{\mu - \lambda} = \frac{\rho}{1 - \rho}$ = 1, 4, 9 and 19 respectively

If the mean service rate is 10 per hour, what is the average time a customer is in the queue for the same traffic intesities?

**$Tq = N/\mu$ = 0.1, 0.4, 0.9, 1.9 hours**

This means when traffic intensity is as high as 0.95, customers will have to wait in the queue for 114 minutes (on average) before being served in 6 minutes (on average).

## Problem:

Material arrives at the average rate of five (5) loads per hour. The material is handled by a fork-lift truck which has an average rate of seven (7) loads per hour.

**Management requires to know:**

a) the average number of loads at the section waiting to be moved, when there is a queue
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c) what the average service-rate must be in order to reduce the expected waiting time to 15 minutes for a load.

**$\lambda = 5$ $\mu = 7$ $\rho = 5/7 = 0.7$**

**Average no. int he queue = $1 / (1 - \rho)$** = 3.4

This means the average no. of loads waiting to be moved when there is a queue = 3.5

Average time in queue = $\rho / \mu (1 - \rho)$ = 0.35 hrs
= 21.4 min

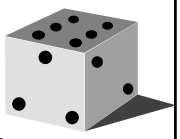
to reduce the waiting time to 15 minutes = 1/4 hr then
$\rho / \mu (1 - \rho) = 1/4$ $\rho = 5/\mu$
**the service rate should be increase from 7 to 7.6 units per hr.**

# SIMULATION

When a system contains elements that **exhibit chance** in their behaviour, the *Monte Carlo* method of simulation may be applied. "experimentation on the chance elements through random sampling".

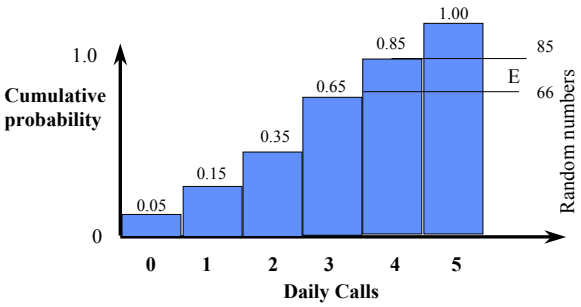
**Simulating randomness**

Each digit has probability 16.6% of occurrence



**Establishing a probability distribution "historical data"**

| Calls for your flatmate | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Frequency (days) | 10 | 20 | 40 | 60 | 40 | 30 |
| Prob. of occurrence % | 5 | 10 | 20 | 30 | 20 | 10 |




If there is a 5% chance that 0 calls per day, then we want 5% of the random numbers available to correspond to 0 calls. So, a simulated 0 calls would be created every time one of these random numbers.

The easy way is to relate the interval of random numbers to the probability of occurrence.

| Calls for your flatmate | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Prob. of occurrence % | 5 | 10 | 20 | 30 | 20 | 10 |
| Interval of Random No. | 1-5 | 6-15 | 16-35 | 36-65 | 66-85 | 86-00 |

4 calls per day occurs 20% of the time. Any of the 20 random numbers (66-85) are assigned to that event.

Generate Random Numbers
52, 37, 82, 69, 98, 96,33 50, 88, 90, 50, 27, 45, 81, 66, 74, 30, 59, 67,

**Simulate the Experiment**

| Calls for your flatmate | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Prob. of occurrence % | 5 | 10 | 20 | 30 | 20 | 10 |
| Interval of Random No. | 1-5 | 6-15 | 16-35 | 36-65 | 66-85 | 86-00 |

| Day Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Random Numbers | 52 | 37 | 82 | 69 | 98 | 96 | 33 | 50 | 88 | 90 |
| Simulated daily calls | 3 | 3 | 4 | 4 | 4 | 5 | 2 | 3 | 5 | 5 |

Total 10-day calls = 38 therefore, average daily calls = 3.8

**Example of Monte Carlo Simulation**

Concrete trucks arriving at a site requiring 20 concrete trucks
It takes about 3 minutes to discharge a truck (2 trucks max. in a queue)

| Arrival time intervals(min) | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Frequency % | 10 | 15 | 30 | 25 | 20 |
| Interval of R. Number | 0-9 | 10-24 | 25-54 | 55-79 | 80-99 |

| Truck No. | 1 | 2 | 3 | 4 | | 11 | 12 |
|---|---|---|---|---|---|---|---|
| R. No. | 89 | 29 | 73 | 50 | | 88 | 2 |
| Arr. time | 6 | 4 | 5 | 4 | | 6 | 2 |
| Cum. time | 6 | 10 | 15 | 23 | | 48 | 50 |

**Example 2**

Two concrete mixers A & B. The daily output of each mixer is as follows:

| **A** | | **B** | |
|---|---|---|---|
| Daily output (CM) | Chance (%) | Daily output (CM) | Chance (%) |
| 0 | 20 | 0 | 10 |
| 7 | 20 | 6 | 30 |
| 8 | 30 | 7 | 40 |
| 9 | 30 | 8 | 20 |

QC tests give each days' output a probability 0.95 of being accepted.

Monitor the daily and cumulative output for a period of 10 days

**Mixer A**

| Daily output | 0 | 7 | 8 | 9 |
|---|---|---|---|---|
| Prob. of occurrence % | 20 | 20 | 30 | 30 |
| Interval of Random No. | 0,1 | 2,3 | 4-6 | 7-9 |

| | (A) | | (B) | | QC | | | |
|---|---|---|---|---|---|---|---|---|
| Day | RN | output | RN | output | RN | test | D. output | C. output |
| 1 | 4 | **8** | 1 | **6** | 79 | Y | **14** | **14** |
| 2 | 0 | 0 | 4 | 7 | 85 | Y | **7** | **21** |
| 3 | 8 | 9 | 0 | 0 | 57 | Y | | |
| 4 | 5 | 8 | 2 | 6 | 68 | | | |
| 5 | 5 | 8 | 1 | 6 | 18 | | | |
| 6 | 6 | 8 | 9 | 8 | 08 | | | |
| 7 | 0 | 0 | 2 | 6 | 27 | | | |
| 8 | 9 | 9 | 2 | 6 | 05 | | | |
| 9 | 1 | 0 | 9 | 8 | 66 | | | |
| 10 | 9 | 3 | 3 | 6 | 39 | | | |

# MATERIALS MANAGEMENT

# STOCK CONTROL

Dr Rodney Stewart

## Material Management

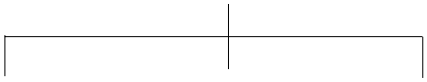
**The Total Cost of Materials**

Cost of materials can be up to 50% of the project cost. Materials control 80% of the project schedule from acquisition to use.

**Material Cost Categories**

| | | |
|---|---|---|
| Price & cost (cost approach) or (negotiated) | Selling price = total product cost + profit | Manufacture cost = factory cost + general exp |

## MANUFACTURER'S VARIABLE COSTS



| Direct Materials | Direct factory labour | Indirect costs |
|---|---|---|
| Raw materials,(20-30%) items required for processing (20-30%) | | scrap, losses, handling testing (25-50%) |

Fixed costs can be seen as overhead, depreciation, **stock control**

**Stock control can be very expensive (20-30% of the cost per year)**

# STOCK CONTROL

Definition:

It is any stored resource that is used to satisfy a current or future need.

Objectives:

To meet the needs of the construction user

To do so in an efficient and cost effective way

To manage a stock:

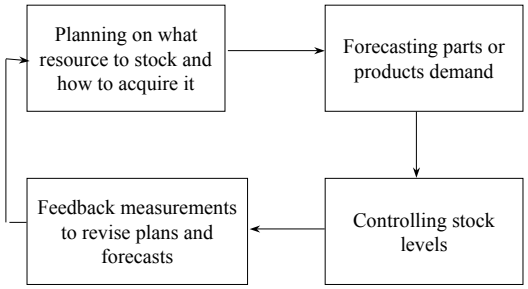
Keep records to tell what is on hand

maintain physical protection and safety

know exact location and control costs

How to get the balance between low and high stock levels ?

# STOCK CONTROL




# STOCK CONTROL DECISION

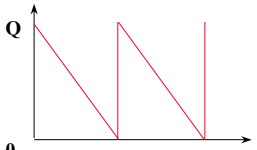
How much to order? When to order?

Cost of the items **Cost of ordering "delivery"** **Cost of holding**
Cost of safety stock Cost of stockouts

| **Cost of ordering** | **Cost of holding** |
|---|---|
| Processing Purchasing order | Cost of capital |
| Inspecting incoming material | Insurance |
| Bill paying | Theft |
| Utilities (phone bills) | Damage |
| Purchasing dept. employees | Warehouse employees |

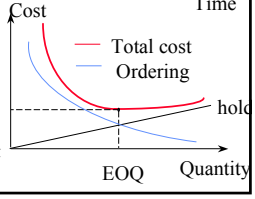
# How much to order?

**BASIC STOCK CONTROL MODEL** Stock level




**Q Order Quantity**
**EOQ Economic Order Quantity**

**Assumptions:**
Demand is known and constant
Lead time is known and constant
The receipt of material is instantaneous
The only variable costs are ordering & holding costs.




**Total cost = ordering cost + holding cost**

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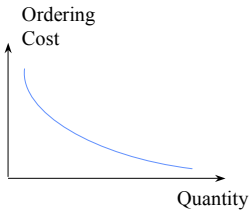
Let there be: Q items in each delivery
the ordering cost for each order be (c)
the annual demand be (d) no. of deliveries = d/Q

**So the annual ordering cost = cd/Q**

If a subcontractor needs 10,000 components per year, and the cost of placing an order is $32, plot the ordering cost as function of Q

Ordering Cost = cd / Q
= 320,000 / Q

| Q | Ordering cost ($) | deliveries |
|---|---|---|
| 100 | 3200 | 100 |
| 200 | 1600 | 50 |
| 400 | 800 | 25 |
| 500 | 640 | 20 |
| 1000 | 320 | 10 |

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Let the value of each item be (p)
the holding cost for a year be proportion (i) of stock value
In other words, the cost of holding one item for a year is (ip)

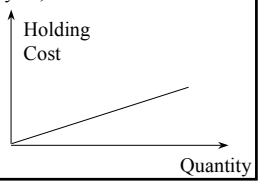
Average stock level throughout the year is Q/2

So the annual holding cost = (ip) Q/2

(Example Continued) If each component is worth $40, and the stock holding costs are 10% of stock value per year, then

p = 40 & i = 0.1
holding cost = 0.1(40) Q/2
= 2.0Q

| Q | 100 | 200 | 400 | 500 |
|---|---|---|---|---|
| Cost($) | 200 | 400 | 800 | 1000 |

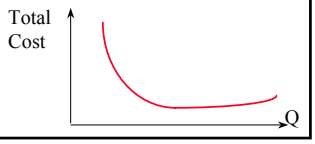


| Q | Ordering cost ($) | Deliveries | Holding cost | Total cost |
|---|---|---|---|---|
| 100 | 3200 | 100 | 200 | 3400 |
| 200 | 1600 | 50 | 400 | 2000 |
| **400** | **800** | **25** | **800** | **1600** |
| 500 | 640 | 20 | 1000 | 1640 |
| 1000 | 320 | 10 | 2000 | 2320 |

So, your **Economic Order Quantity** is 400 at a time

It is obtained at the point where Ordering cost is equal to holding cost

$$Q = \sqrt{\frac{2cd}{ip}}$$

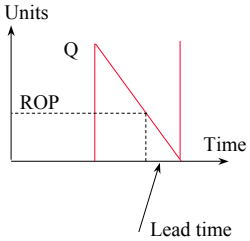



## When to order?

So far in this model, we assumed that the receipt of an order is instantaneous

But you need to know the reorder point

ROP = (Demand per day) (lead time)




Your demand is 8,000 units per year (daily demand of 40)
On the average, delivery of an order takes 3 working days

ROP = (40) (3) = 120 Units

Example (1):

You have to order components in batches of 150 units. It has been estimated that annual demand for these components is 250. Furthermore, holding cost is estimated to be $1 per unit per year. For the order policy to be optimal, determine what are the ordering cost would have to be?

Solution Q = 150, d = 250 ip = $1

$$Q = \sqrt{\frac{2cd}{ip}} \longrightarrow c = Q^2 (ip/2d) = \$45$$

Example (2):

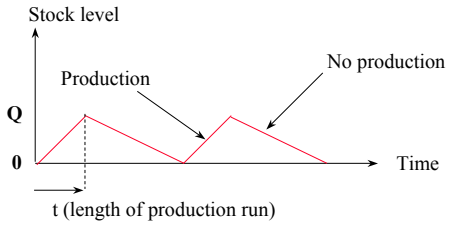
Annual demand is 40,000 units, ordering cost = $15 per order
holding cost is $3 per unit per year
If there are 160 working days per year, find the daily demand
and the optimal number of days between orders?

Solution d = 40,000 c = $15 ip = $3

So optimal Q = $\sqrt{\frac{2cd}{ip}}$ = 632 units

Optimal no. of orders per years = 40,000/632 = 63.3 = 64
Daily demand = 40,000 / 160 = 250 units
Optimal no. of days between orders = 160/ 64 = 2.5 working days

## STOCK LEVEL AS A FUNCTION OF TIME




- The batch will not arrive all at once but is built up at uniform rate.
- Stock refers to **products**.
- As soon as stock runs out, the producer immediately embarks on production of new batch. While production of this batch is still going on, items made earlier can be sold.
- We will have a set-up cost (cost for setting-up production).

## How much to order?

**Cost of Set-up (very similar to ordering cost):**

(c) set-up cost per batch, (d) demand (sell) rate, (Q) items per batch

No. of batches = d / Q & **Annual set-up cost = cd / Q (1)**

**Cost of Holding:**

Annual cost of holding = average stock level * holding cost per unit/year
**Average stock level = 0.5 (maximum stock level)**
Max. stock level = (total **produced** during the production run) –
(total **used** during the production run)

If I produce Q items per batch then Q = r t
where r no. of produced items per year of production time

Therefore,
total produced – total used = rt – dt = (r – d) t
= (r – d) (Q / r )
= Q(1 – d/r)

**Annual holding costs = 0.5 Q (1 – d/r) (ip) (2)**

| Production Run Model | Basic Stock Control Model |
|---|---|
| $Q = \sqrt{\frac{2cd}{ip\,(1-d/r)}}$ | $Q = \sqrt{\frac{2cd}{ip}}$ |

d selling rate
r production rate

Example:

A company sells items at the rate of 500 per day throughout a year of 250 days. It can produce at a rate of 800 per day with a set-up cost per batch of $600 and a cost per item of $4.
If the proportionate stock-holding cost is 25% of stock value per year, find the economic batch quantity?

Solution:
d = 500 (250) = 125000 items per year (1-d/r) = 0.375
r = 800 (250) = 200000 items per year
Set-up cost per batch = $600
ip = 0.25 (4) = $1 per year

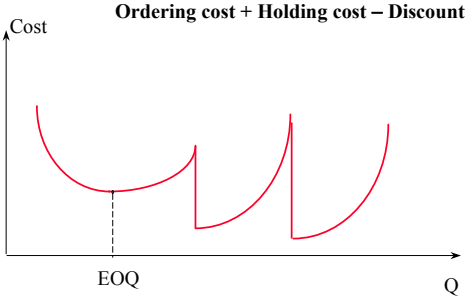
$$Q = \sqrt{\frac{2cd}{ip\,(1-d/r)}}$$

$$Q^2 = \frac{2\,(600)\,(125{,}000)}{1\,(0.375)} = 20{,}000$$ ie. produce in batches of 20,000

## STOCK CONTROL WITH DISCOUNTS

Discounts are available for large orders

**Ordering cost + Holding cost – Discount savings**



**Example:** If a firm is able to obtain quantity discounts on its orders as shown below, **calculate the best quantity to order**.

| **Price per ton ($)** | **Tons bought** |
|---|---|
| 6.0 | 1- 249 |
| 5.9 | 250-799 |
| 5.8 | 800-1999 |
| 5.7 | 2000-3999 |
| 5.6 | 4000 and over |

The ordering cost (c) = $6, annual demand (d) = 4000 tons holding cost are 20% of material cost.

$$Q = \sqrt{\frac{2\,(6)\,(4000)}{0.2\,(6)}} = 200 \qquad Q = \sqrt{\frac{2cd}{ip}}$$

| Q | (1) ordering c d/ Q =24,000/Q | (2) holding 0.5Q(ip) = 0.1Q | (3) discount savings 4000 (6-p) | (1)+(2)– (3) |
|---|---|---|---|---|
| 200 | 120 | 120 | 0 | 240 |
| 250 | 96 | 147.5 | 400 | -156.5 |
| 800 | 30 | 464 | 800 | -306 |
| 2000 | 12 | 1140 | 1200 | -48 |
| 4000 | 6 | 2240 | 1600 | 646 |

Buy in batches of 800 tons.

**Example:** Given the following information, what order quantity will minimise the total stock control cost.

| Discount | Quantity | Cost per item |
|---|---|---|
| 1 | 1-999 | $50 |
| 2 | 1000-1999 | $48 |
| 3 | > 2000 | $46 |

$$Q = \sqrt{\frac{2cd}{ip}}$$

The ordering cost per order $490, annual demand = 5000, and holding cost is 0.2 of item cost.

**Solution:** Calculate Economic Order Quantity for each discount

$$Q1 = \sqrt{\frac{2(5000)\,(490)}{0.2\,(50)}} = 700 \text{ items}$$

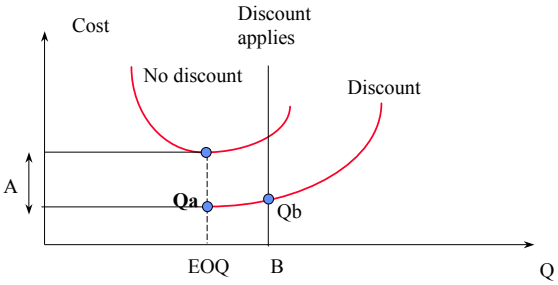
**Q2** ***= 714 items*** **Q3** ***= 730 items*** ***They have to be adjusted***

Why do we need to adjust Q2 and Q3?
Simply because a quantity Q within the discount range may result in the lowest total cost.

Annual Material Cost = annual demand (d) * cost per unit (1)
Annual Ordering Cost = c d / Q (2)
Annual Holding Cost = 0.5 Q (ip) (3)

| Discount | Unit price | Q | (1) 000's | (2) 000's | (3) 000's | Total ($) 000's |
|---|---|---|---|---|---|---|
| 1 | $50 | 700 | 250 | 3.5 | 3.5 | 257 |
| 2 | $48 | 1000 | 240 | 2.45 | 4.8 | 247.25 |
| 3 | $46 | 2000 | 230 | 1.23 | 9.2 | 240.4 |

Select the order quantity with the lowest total cost. An order of 2,000 minimises the total cost.




Point Qa for the discount is < than allowable range. But Point Qb is the one that gives rise to the minimum total cost.
We try to ensure that we do not discard an order quantity that may indeed produce the minimum cost.

## HUMAN RESOURCES PLANNING

**Purpose:** To maintain an adequate supply of suitable experienced labour.

To reduce overmanning during downturns in demand

To avoid sharp fluctuation in each trade.

**Factors Influencing Demand & Supply of Labour**

Wages & Rewards
Skills
Other factors such as
Geographical location, working conditions, Social

## INCENTIVES

1. **Daywork** (function of time $ per hour)

2. **Piecework** (uniform price per unit of production), the incentive is to produce more. (repetitive work)

3. **Standard System** (money is the target)
This is the job, it needs a max. of 8 hours

4. **Hours-saved System** (bonus is earned if performance exceeds agreed standards)

**A good scheme should allow for**
(1) A bonus to be paid in direct proportion to the effort applied.
(2) The earnings should not be limited
(3) No sub-standard work is allowed (penalty is involved).

## ALLOCATION

Assumptions:
1. No. of People (rows) = No. Tasks (columns)
2. The numbers within the matrix are the costs associated with each particular task.

Say you have three rushed tasks (T1), (T2) & (T3)
and you have **ADAMS, BROWN and COOPER**
are available to perform tasks at different speed/cost).

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | $11 | $14 | **$6** |
| BROWN | $8 | **$10** | $11 |
| COOPER | **$9** | $12 | $7 |

Six alternatives are available 3! = 3(2)(1) = 6.

# MATRIX REDUCTION

What we need is an a method that can provide us with an efficient means of finding the **OPTIMAL** solution without having to make a direct comparison of every option.

(1) **Create a matrix of opportunity cost**.

Subtract the smallest no. in **each row** of the original cost matrix from every number in that **row**, and THEN

Subtract the smallest number in **each column** of matrix obtained from every number in that **column**.

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | $11 | $14 | **$6** |
| BROWN | **$8** | $10 | $11 |
| COOPER | $9 | $12 | **$7** |

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | 5 | 8 | 0 |
| BROWN | 0 | **2** | 3 |
| COOPER | 2 | 5 | 0 |

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | 5 | 6 | 0 |
| BROWN | 0 | 0 | 3 |
| COOPER | 2 | 3 | 0 |

(2) Connect "zeros" either vertically or horizontally and then compare the no. of lines (N), we are after the minimum number of straight lines needed to cover ALL "zeros".
If (N) = number of rows/columns Optimal solution

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | 5 | 6 | 0 |
| BROWN | 0 | 0 | 3 |
| COOPER | **2** | 3 | 0 |

(3) Subtract the smallest number "not covered" from **EVERY** other uncovered number and then add the same number to the intersection of any 2 lines even if it was (0).

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | 3 | 4 | **0** |
| BROWN | 0 | **0** | 5 |
| COOPER | **0** | 1 | 0 |

You can have an optimal solution by **Maximising efficiency**

**Example:**
The only difference is that you need to convert the matrix first into a minimising opportunity cost table and then proceed with the previous three steps as before.

| | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| ADAMS | 20 | 60 | 50 | 55 |
| BROWN | 60 | 30 | 80 | 75 |
| COOPER | 80 | **100** | 90 | 80 |
| DAVIS | 65 | 80 | 75 | 70 |

| | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| ADAMS | 80 | **40** | 50 | 45 |
| BROWN | 40 | 70 | **20** | 25 |
| COOPER | 20 | **0** | 10 | 20 |
| DAVIS | 35 | **20** | 25 | 30 |

| | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| ADAMS | 40 | 0 | 10 | **5** |
| BROWN | 20 | 50 | 0 | 5 |
| COOPER | 20 | 0 | 10 | 20 |
| DAVIS | **15** | 0 | 5 | 10 |

| | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| ADAMS | 25 | 0 | 10 | 0 |
| BROWN | 5 | 50 | 0 | 0 |
| COOPER | 5 | 0 | 10 | 15 |
| DAVIS | **0** | 0 | 5 | 5 |

4 Straight lines covering all zeros in the matrix Optimal Solution:
Cooper will definitely perform Task T2 (100%)
Davis will perform Task T1 (65%)
Brown Task 3 (80%) & finally Adams will perform Task 4 (55%)

## Matrix Reduction Question

Your company has one surplus truck in each of the towns A, B, C, D, and E and one deficit truck in each of the construction sites 1, 2, 3, 4, 5 and 6. The distance between the towns and the construction sites in kilometres is shown in the matrix below (see Table 1). Assign the trucks from towns to construction sites to minimise the total distance covered.

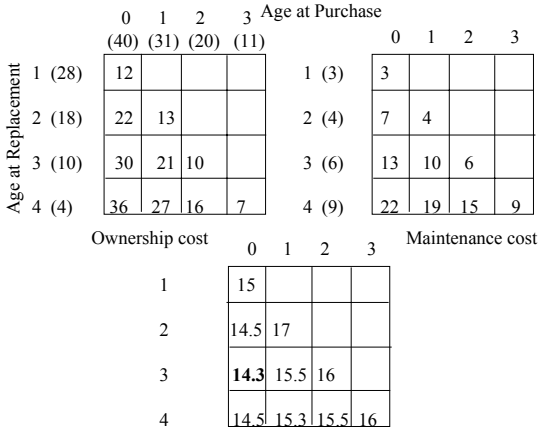
| | **Site 1** | **Site 2** | **Site 3** | **Site 4** | **Site 5** | **Site 6** |
|---|---|---|---|---|---|---|
| **A** | 12 | 10 | 15 | 22 | 18 | 8 |
| **B** | 10 | 18 | 25 | 15 | 16 | 12 |
| **C** | 11 | 10 | 3 | 8 | 5 | 9 |
| **D** | 6 | 14 | 10 | 13 | 13 | 12 |
| **E** | 8 | 12 | 11 | 7 | 13 | 10 |

## EQUIPMENT PLANNING

**You need to buy an equipment**

| Age at Purchase | Price (k) | Age of machine | Resale (k) | Maintenance (k) |
|---|---|---|---|---|
| 0 | 40 | | | |
| 1 | 31 | 1 | 28 | 3 |
| 2 | 20 | 2 | 18 | 4 |
| 3 | 11 | 3 | 10 | 6 |
| | | 4 | 4 | 9 |

Determine what age of machine should be purchased and when it should be replaced.




## Comparing Productivity

Two equipment A & B are being considered for aggregate production. (1kg of aggregate to be sold for $0.25).

Equipment A can produce 500,000 kg per year and costs $150,000 to buy. It has an expected life of 10 years (assume 12 working hrs/day). Annual expenses amount to $100,000. Equipment A has a production rate of 250 kg/hr.

Equipment B is highly automated and costs $240,000 and has an expected life of 12 years working a single 8hr shift/working day. Annual expenses for B amount to $90,000. B has a production rate of 300 kg/hr.

Assume 250 working days / year.

**Equipment A**

It requires 500,000/(250) = 2,000 hrs of production/year

Operating life = 10 years working 12 hrs day
= 12 (250) = 3,000 hrs / yr.

Life expected at the 2,000 hrs/year rate = 10(3,000)/2,000 = 15 years

| | | |
|---|---|---|
| Income = 500,000 (0.25) | = $125,000 | per year |
| less expenses | = $100,000 | |
| Profit | = $25,000 | |

So you need to invest $150,000 to get $25,000 per year for **15 years**

i = 14.1%

**Equipment B**

It requires 500,000/ (300) = 1,666 hrs of production/year

Operating life = 12 years working 8hrs day
= 8 (250) = 2,000 hrs / yr.

Life expected at the 1,666 hrs/year rate = 12(2,000)/1,666 = 15years

| | |
|---|---|
| Income = 500,000 (0.25) | = $125,000 |
| less expenses | = $ 90,000 |
| Profit | = $ 35,000 |

You need to invest $240,000 to get $35,000 per year for 15 years

i = 12%

Therefore, A is the best proposition.

## DECISION MAKING

### D.M. under Risk

| | Boom | Recession |
|---|---|---|
| Buy a large-capacity machine | 200,000 | –180,000 |
| Buy a small-capacity machine | 100,000 | – 20,000 |
| Buy nothing | 0 | 0 |

This is highly dependent on the probability of having a recession, say it is 50/50 for this example

For each alternative, calculate the **Expected Monetary Value** (EMV)

EMV (1) = 0.5(200,000) – 0.5 (180,000) = $10,000
EMV (2) = 0.5(100,000) – 0.5 (20,000) = $40,000

Select the option with the **maximum (EMV) Buy the small one.**

## Opportunity Loss

we can achieve the same answer, if we create an opportunity loss table (**how much will it cost me if I do not choose the best alternative**)

| | Boom | Recession |
|---|---|---|
| Buy a large-capacity machine | **200,000** | -180,000 |
| Buy a small-capacity machine | 100,000 | - 20,000 |
| Buy nothing | 0 | **0** |

**Opportunity Loss Table**

| | Boom | Recession |
|---|---|---|
| Buy a large-capacity machine | 200,000 - 200,000 | 0 - (-180,000) |
| Buy a small-capacity machine | 200,000 - 100,000 | 0 - (-20,000) |
| Buy nothing | 200,000 - 0 | 0 - 0 |

| | Boom | Recession |
|---|---|---|
| Buy a large-capacity machine | 0 | 180,000 |
| Buy a small-capacity machine | 100,000 | 20,000 |
| Buy nothing | 200,000 | 0 |
| **Probability** | 0.5 | 0.5 |

**Expected Opportunity Loss** (large) = 0.5(0) + 0.5(180,000) = $90,000
EOL (small)= 0.5(100,000)+ 0.5(20,000)= **$60,000**
EOL (nothing) = 0.5(200,000) + 0.5(0) = $100,000

Using the Minimum Opportunity Loss as my decision criterion, then **Go for buying the small equipment**. The same answer as obtained earlier using Maximum EMV.

Suppose you **can be sure** of the market status (boom/recession), if you conduct a market analysis

This will give you a **perfect answer**, **however it will cost you**

**How much You are ready to spend to get this perfect answer?**

The following two terms will help you make the right decision

The Expected value **with** Prefect information (EP) =

Σ (best outcome for boom/recess.)* (probability of its occurrence)
&
The Expected Value **of** Prefect Information (EVPI)

EVPI = EP – Max. EMV

| | Boom | Recession |
|---|---|---|
| Buy a large-capacity machine | 200,000 | -180,000 |
| Buy a small-capacity machine | 100,000 | - 20,000 |
| Buy nothing | 0 | 0 |

Maximum EMV = $40,000

The best outcome "Boom" = $200,000
The best outcome for "Recession" = $0

The expected value with perfect information (EP)=

(200,000)(0.5) + (0) (0.5) = $100,000

EVPI = 100,000 – 40,000 = $60,000 = Minimum EOL

So Do not pay more than 60,000 for the **PERFECT** information

## D.M. under Uncertainty

When the probability of occurrence can be assessed,
Max. EMV or Min. EOL can be used, but what happens if you cannot assess the outcome probability.

In our example, we assumed **50/50** chance... What happens if we have no clue about the situation? This is **Uncertainty.**

Because I have no clue, I can be a **gambler** (optimistic) "max. profit" or **conservative** (pessimistic) "min. loss".

| | **Boom** | **Recession** |
|---|---|---|
| Buy a large-capacity machine | **200,000** | –180,000 |
| Buy a small-capacity machine | 100,000 | – 20,000 |
| Buy nothing | 0 | **0** |

Or You can simply go for the highest average outcome

Average!!! (sound like 50/50 again).

| | **Boom** | **Recession** | **Av./2** |
|---|---|---|---|
| Buy a large-capacity machine | 200,000 | –180,000 | 10 k |
| Buy a small-capacity machine | 100,000 | – 20,000 | **40 k** |
| Buy nothing | 0 | 0 | 0 |

Or finally, go for the ***Expected opportunity Loss***

| | Boom | Recession | Max. |
|---|---|---|---|
| Buy a large-capacity machine | 0 | 180,000 | 180k |
| Buy a small-capacity machine | 100,000 | 20,000 | **100k** |
| Buy nothing | 200,000 | 0 | 200k |

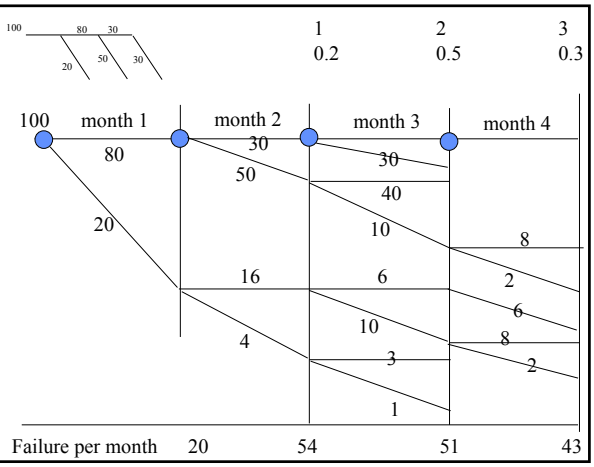
**Go for the alternative that minimises the maximum EOL**

## Replacement Strategy

A set of 100 lamps is used to give warning of a series of roadworks. Each lamp is powered by a battery which is expected to fail sometime during a period of 3 months. Replacement of of failed batteries may take place only at the end of the month (to replace each failed battery it costs $10.

You may choose to replace the whole set for $600 (whether failed or not). The following table gives data relating to the survival of the batteries:

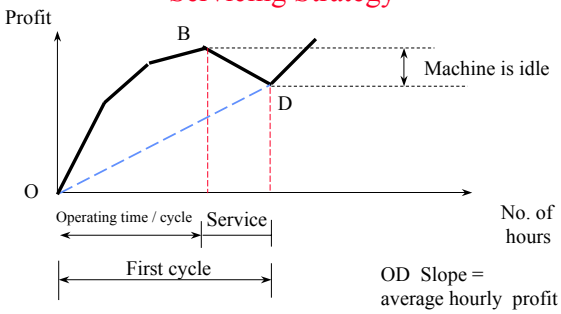
| Month of Use | 1 | 2 | 3 |
|---|---|---|---|
| Probability of failure during this month | 0.2 | 0.5 | 0.3 |




| Failure per month | 20 | 54 | 51 | 43 |
|---|---|---|---|---|
| Cumulative failures | 20 | 74 | 125 | 168 |

| End of month | Cumulative cost ($) | Group replacement Cost ($) | Total cost |
|---|---|---|---|
| 0 | 0 | | |
| 1 | 200 | | |
| 2 | 740 | | |
| 3 | 1250 | | |
| 4 | 1680 | | |

## Servicing Strategy




OD Slope = average hourly profit (s)

Loosing efficiency as the equipment operates means that the rate at which it generates profit declines. It is essential to service the equipment periodically to restore its maximum efficiency.

**Example**:

The gross profit P ($) has been expressed as a function of no. of hours the equipment has operated since it was last serviced X

$P = 280X - 1.2X^2$

The cost of service is $860, and the idle time is 3.5 hours. Determine how frequently the machine should be serviced, to the nearest hour, and the average hourly profit that accrues from use of the machine.

Net profit = $280X - 1.2X^2 - 860$
First cycle takes $X + 3.5$ hours
So $S = (280X - 1.2X^2 - 860) / (X + 3.5)$
By differentiating and equating to zero

$(X + 3.5)(280 - 2.4X) - (280X - 1.2X^2 - 860)(1) = 0$

or $1.2X^2 + 8.4X - 1480 = 0$

$X = 36$ hrs  $S = \$194$ per hour

Note that if the service cost drops say from $860 to $620 then

$X = 33$ hrs  $S = \$200$ per hour

As the service cost gets reduced, it becomes economical to service the machine more frequently and thereby secure higher average efficiency.

# Example (please try)

A contracting organisation is going to purchase one of three types of real estate. The organisation must decide among, an apartment building, an office building, and a warehouse. The future states of nature that will determine how much profit the organisation will make are good economic conditions and poor economic conditions. The profits that will result from each decision in the event of each state of nature are shown in the following table:

| **Decision (purchase)** | **Good Economic conditions** | **Poor economic conditions** |
|---|---|---|
| Apartment building | $50,000 | $30,000 |
| Office building | $100,000 | - $40,000 |
| Warehouse | $30,000 | $10,000 |

Determine the best decision using two (2) different methods, assuming probabilities that good or poor economic conditions will occur in the future are 0.6 and 0.4, respectively.

# COST MANAGEMENT

Dr Rodney Stewart

## COST FUNDAMENTALS

**Production Cost**

A combination of Factors of Production
Calculating cost on the basis of combining these factors.

Fixed, Variable and Semi-variable Costs

**Equipment**

**Fixed costs** tend to be unaffected by the amount of work
**Variable costs** incurred in proportion to the amount of work
**Semi-variable costs** "difficult to be predetermined with precision".

## ESTIMATING

**The purpose:**

1. used for planning & forecasting to assist in the economic and financial assessment of the investment
2. control estimates exercised during design to ensure that the economic assessment remain valid as the design progresses.
3. tendering estimates enable the contractor to prepare a bid

In estimating "forecasting" the total cost **"statistical data"**

# COST PLANNING

There are 4 basic trends which are invaluable in economy forecasting

1. **The arithmetic trend** "directly proportional" $Y = a + bx$

2. The semilogarithmetic trend "exponential curve"
3. The logarithmic trend "data plotted on log-log paper.

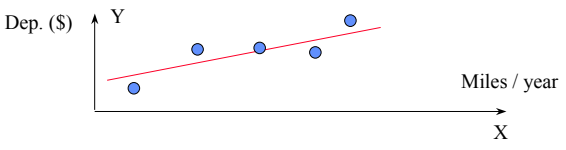
4. **The S curve** "statistical data corresponding to **cumulative** normal distribution".
   Slow start, picking up to a gradually increasing rate and finally tapering off to a steady level.
   Used mainly in **Cash Flow** forecasting.

## Method of Least Squares

Fitting of a curve to a set of collected data by means of minimising the sum of the squares of the distances from the fitted line to the points.

**Example:**
A fleet of vehicles have been run for different distances during the 1st year of operation, you are required to establish a ratio of the total depreciation in their value to the distance run.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Dep. ($) | Y | 6000 | 6100 | 7000 | 6000 | 7800 | 6800 | 8000 |
| Mileage run | X | 6 | 8 | 8.8 | 9.6 | 10.4 | 12.8 | 12.8 |
| Dep. ($) | Y | 7400 | 8600 | 7400 | 8800 | 10000 | | |
| Mileage run | X | 14 | 16 | 17.2 | 9.6 | 10.4 | | |



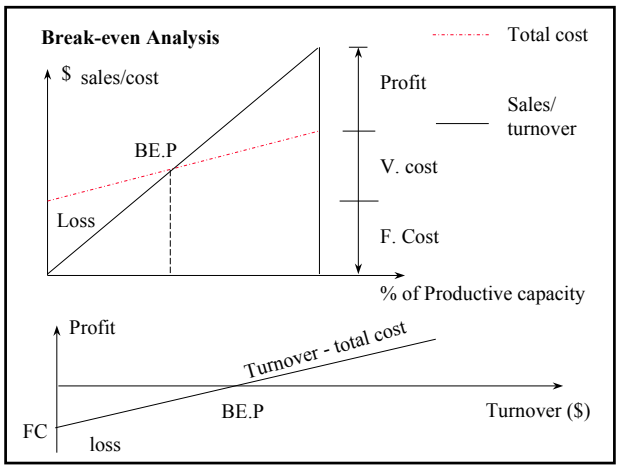

**$Y = mx + b$** where m is the slope

It is now required to get **(b)** and **(m)** for a line which gives the best fit.

Values of m and b are calculated so as to minimise the deviations

Deviation: the diff. between the y-value of the line and the y-value for the point (original point) for a particular value of x.

$$m = \frac{n \Sigma XY - (\Sigma X)(\Sigma Y)}{n \Sigma X^2 - (\Sigma X)^2} \qquad b = \frac{\Sigma X^2 (\Sigma Y) - (\Sigma X)(\Sigma XY)}{n \Sigma X^2 - (\Sigma X)^2}$$




**Example (please try)**
A contractor bases his estimate on an annual output of 16,000 Cm of concrete (100% productivity). He assumes that concrete will be sold for $50.0/ Cm. So his turnover = $800,000 / year

Fixed cost = $135,000 (hiring or buying the plant)
Variable cost = $533,000 (labour, material, etc.) if 100% capacity.

(a) What is the profit per year? Per Cm?

(b) What happens if the contractor produces 10,000 Cm/year ?

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Fixed cost = $135,000 (hiring or buying the plant)
Variable cost = $533,000 (labour, material, etc.) if 100% capacity.

The contractor can make a profit of = 800,000 - 135,000 – 533,000
= $132,000/ year

What happens if the contractor produces 10,000 Cm/year ?

Income from sales = 500,000
less fixed cost = 500, 000 – 135,000 = 365,000
less variable cost = 365,000 – 533,000 (10/16) = $31,875

The profit falls from an expected $8.25/Cm to $3.20

**EXAMPLE:**

A material supplier company produces 18,000 items per year when working at 60% of the factory's capacity. Each item is sold for $10. The costs involved in the manufacture at this rate of production are as follows:

- Materials $35,000
- Wages $60,000
- Fixed overhead costs $25,000
- Variable overhead costs $15,000

**Note**: Variable overhead is constantly proportionate to the number of items produced.

A contractor places an order with the company for 12,000 additional items at the reduced price of $8.75 each (i.e. now 100% production). Due to the additional quantity of materials that are required, a 5.0% discount on previous prices is obtained but only for the additional work. However, the additional labour that is required has to be drawn from a reservoir of untrained labour. As a result, the overall efficiency of labour in production throughout the factory falls by 10% on all production.

**(a) Illustrate the variation in profit between the prior and new situation.**
**(b) Which is the best option, based on percentage profit?**

**SOLUTION:**

Situation A
Cost = 35,0000 + 60,000 + 25,000 + 15,000 = **$135,000**
Earnings = 18,000 × 10 = **$180,000**
Profit = **$45,000**
Per cent profit = 45,000/135,000 × 100 = **33.3 %**

Situation B
Cost = [35,000 + (12000/18000 × 35,000) /1.05] + [(60,000 + 60,000 × 12/18) × 1.1] + 25,000 + 15,000(30/18) = **$217,222**
Earnings = $180,000 + 12,000 × 8.75 = **$285,000**
Profit = 285,000 – 239,222 = **$67,778**
Per cent profit = 67,778/217,222 = **31.2%**

Based on percentage profit, the first option is the best.

# THE COSTING PROCESS

It is the process which results in the establishment of the cost of carrying out an operation (workpackage, the whole project)

**Costing vs. Accounting** (Book-keeping)
Accounting is recording data in such a way that cost can be readily identifiable. It gives little info. upon which management can take action.

| **Site Account** for Contract B4297 | | | **Cost Account** | | | |
|---|---|---|---|---|---|---|
| | | | Excav. | Piling | Concrete | Total |
| Materials | 24 k | | 0 | 10 k | 14 k | 24 k |
| Wages | 30 k | | 6 k | 5 k | 19 k | 30 k |
| Plant | 20 k | | 12 | 6 | 2 | 20 |
| Overheads | 7 k | | 1 | 2 | 4 | 7 |
| Profit | **8** k | Cost | 18 | 26 | 45 | 89 |
| Total | 89 k | Profit | -1 | 3 | 6 | **8** |

## Why do we need Costing?

1. To provide info. that enables periodic statement of profit/loss to be drawn up for each project at regular intervals of time.
2. To highlight activities (in trouble)
3. To provide cost data on which management can act
4. To enable estimators to get feedback information.
5. To provide info. regarding "others" eg. equipment/subcontractors

## CONTRACT COSTING

A system of costing which is used in the industry. A separate contract account is allocated to each contract. A number of sub-accounts can be created.

**OVERHEADS**

**A fixed budget** is one that takes no account of **varying rates of production "of limited value only".**

**A flexible budget** is such that certain elements of the budgets are established for different levels and/or rates of production.

| **Example** | **Standard** | **Flexible** |
|---|---|---|
| Monthly turnover ($) | 100,000 | 110,000 |
| Output | (100%) | (110%) |
| **Overheads:** | | |
| Supervisory staff | 10,000 | 10,000 |
| Office staff | 2,000 | 2800 |
| Office expenses | 700 | 740 |
| Printing | 150 | 180 |
| **TOTAL** | **12,850** | **13,720** |

## COST MANAGEMENT

**Actual Cost** vs. **Estimate** for corresponding work

The earned value analysis integrates cost, schedule and work performed by ascribing monetary values to each (eg. Microplanner tutorial).

The difference between the forecast final cost and the estimated cost is called the **Variance**.

Any noted variance must be analysed.

**Example**:

A contractor is 52 weeks into a 76-week project which is on schedule. To date he has spent $85,000 on labour. The estimate for the total cost of labour for the project was $98,500. Find the forecast final cost. Assume that all other conditions are the same now as when project started.

**Example**: A contractor is 52 weeks into a 76-week project which is on schedule. To date he has spent $85,000 on labour. The estimate for the total cost of labour for the project was $98,500. Find the forecast final cost. Assume that all other conditions are the same now as when project started.

%age of work completed = (52/76) * (100) = 68.4%

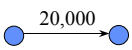
Forecast final cost = 85,000 + 85,000 (100-68.4) / 68.4 =
$85,000 + $39,269 = $124,269
**Variance** = $25,769

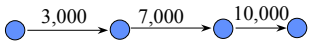
The contractor now has a chance to make changes in the remaining work to reduce the variance.

**Network-based Model**

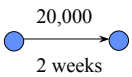
There are 2 methods whereby cost control can be applied through networks. These are:

1. **Rigidly tied costs**
   Costs are distributed over the various network activities.



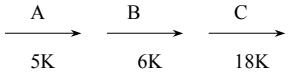




2. **Semirigidly tied cost** "cost is related to a time span covering a number of activities".




Week 1 $5,000, Week 2 $15,000

**Example:**




A 100% complete
B 50% complete
C 60% complete

Project cost to date = 5,000 + 0.6 (6,000) + 0.5 (18,000) = $17,600

## The Significance of Cash Flows

The owner wants to minimise total investment (interest charges)
The contractor wants to minimise the working capital needed.

Availability of **Working Capital** is **VITAL.**

## DESIGN COSTS

The more detailed design that is undertaken, the more definitive becomes the estimate.

There is a need to implement a cost control process to meet the following objectives:

1. Achievement of the owner's financial budget in relation to the design and construction costs resulting from the investment.
2. Achievement of the owner's objective to have a facility which will have the capacity that was specified at the appraisal stage.
3. Getting some indication of the physical progress of the work in relation to the plans and schedules.

During the design stage, every opportunity must be taken to keep the cost of the designed facility to a minimum.

**Example (please try):**

The total length of a proposed bridge is 740 m. The total weight of structural steel in the superstructure for each span can be found using this formula

$$W = 150 L^2 + 900 L$$

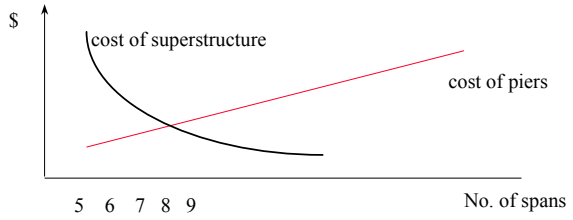
L is the length of each span in (m), W is the weight in kg

If the steel in the superstructure costs $400 per 1000 kg including fabrication & erection, and the total cost of one pier is $400,000

Find the best practical length of each span to achieve **minimum cost** (assuming equal length).

**Solution:**

| No. of spans | Length (m) | Superstructure ($) | Piers ($) | Total |
|---|---|---|---|---|
| 5 | 148.0 | 6,837,600 | 2,400,000 | 9,237,600 |
| 6 | 123.3 | 5,742,400 | 2,800,000 | 8,542,400 |
| 7 | 105.7 | 4,960,114 | 3,200,000 | 8,160,114 |

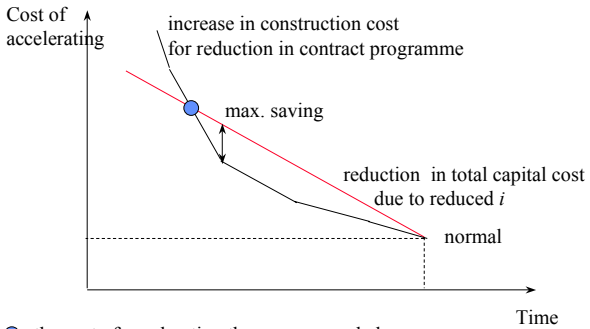



## Expenditure forecasting

The owner needs to have an indication of the phasing of the payments that will have to be made.

| Activities | Months | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| A | 100 | 100 | | | | | |
| B | | 90 | 50 | 200 | | | |
| C | | | 100 | 80 | 80 | 80 | |
| D | | | | | 90 | 110 | |
| E | | | | | | 60 | 20 |
| Total | 100 | 190 | 150 | 280 | 170 | 250 | 20 |
| Cumulative | 100 | 290 | 440 | 720 | 890 | 1140 | 1160 |

## Owner's optimum construction programme




- the cost of accelerating the programme balances savings in interest payments

## Project Budgetary Control

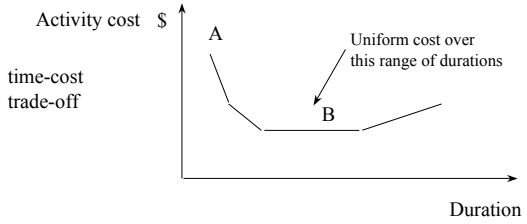
**Revised Budget = Original estimated budget + Project variance**

| End of month | Budgeted value of work to be completed | Budget value of work completed | Budget value of work to completion | Total budget of work as planned | Actual cost of work completed | Revised cost estimate of work | Revised total estimated cost |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 =1+3 | 5 | 6 | 7=5+6 |
| 1 | 10,000 | 8,000 | 90,000 | 100,000 | 9,000 | 93,000 | 102,000 |
| 2 | 25,000 | 18,000 | 77,000 | 102,000 | 25,000 | 81,000 | 106,000 |
| 3 | 50,000 | 45,000 | 56,000 | 106,000 | 47,000 | 67,000 | 114,000 |

Variance is $2,000 at the end month 1, $6,000 at end of month 2,

**Network analysis as a basis for cost control**

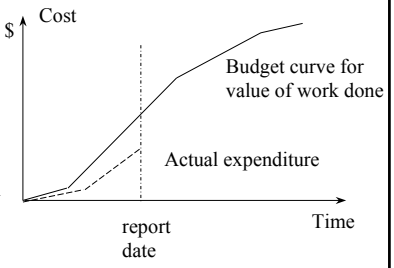
When a total cost for a project is established, it must be established on the basis that a programme has been drawn up for the time performance of the work involved.



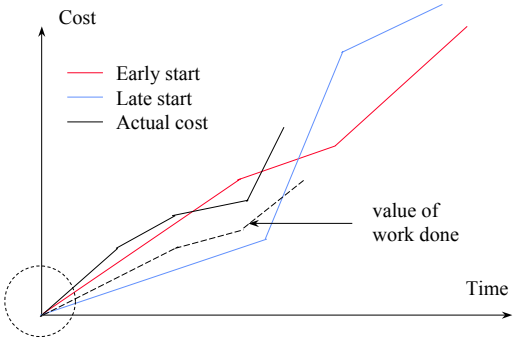

A No further reduction in duration
B Optimum cost may be over a range of resource combinations

Cost cannot be controlled in isolation; there is a need to control it with a control of time.

It is sometimes wrongly assumed that whenever the actual expenditure curve keeps below the budget curve for value, the cost of the work is being controlled effectively.




There are two (2) scenarios:
1. the work may have been completed more cheaply than budgeted.
2. not as much work has been completed as was planned for this period




If the progress of work at estimated cost is to be maintained in accordance with the targets set by the budget and the network analysis, then the curve of 'value' must pass between the envelope.

**Risk for an owner**

Risk and cost are directly proportional one to the other. In general, the **greater the risk** that exists, **the greater the premium** that must be paid to insure against it and the greater the possibility that larger costs will be incurred than were originally foreseen and not anticipated.

The Owner's Role

- Requirements
- Funds
- General Organisation (approach)
- Risk sharing

types of risks: (as far as cost is concerned)

Price, inflation, work nature, delays, industrial relations, weather, lack of funds, and many more.

**Example:**

Three estimates of the **annual operating cost** of a proposed new plant are given together with the associated probability that any one of them will be achieved. (all costs are in $000). The costs are $1000, $1100 and $1200 having probabilities of 0.3, 0.5 and 0.2, respectively.

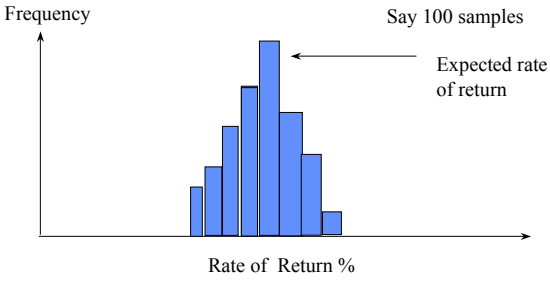
**Annual revenue** is estimated to be $4400, $4500, $4600 or $4700 having probabilities of 0.1, 0.3, 0.4 and 0.2, respectively.

In estimating **the capital cost**, the project manager believes that there is a 0.3 probability of it being $14,000, a 0.6 probability of it being $15,000 and 0.1 prob. of it being $16,000

The **three lives** and their associated probabilities are five years and 0.4, six years and 0.3 and seven years with a probability of 0.3.
Assess the risk in making this investment..

For each one of the four variables we need to assign a probability distribution. (random numbers say 00-99) Selected numbers are 13, 25, 62, 9, 37, 91, 80,.....

| Random No. | Ann. operat. cost | Ann. rev. | Capital cost | Project life (years) | Net ann. Rev. | Rate of return |
|---|---|---|---|---|---|---|
| 13 | 1000 | 4500 | 14,000 | 5 | 3500 | i1 % |
| 25 | 1000 | 4500 | 14,000 | 5 | 3500 | i2 % |
| 62 | 1100 | 4600 | 15,000 | 6 | 3500 | i3 |
| 09 | 1000 | 4400 | 14,000 | 5 | 3400 | i4 |
| 37 | 1100 | 4500 | 15,000 | 5 | 3400 | i5 |
| 91 | 1200 | 4700 | 16,000 | 7 | 3500 | i6 |
| 80 | 1200 | 4700 | 15,000 | 7 | 3500 | i7 |




The term **Expected** is used with reference to the most probable value of frequency or probability distribution.
It is the value of the variable that has the greatest probability of occurring.

**Example (please try):**
A company is reviewing its investment policy. It has two $10,000 investment in Projects categorised A. A $20,000 and $30,000 investments in Projects categorised B. A $30,000 investment in Project C. All projects are considered to have a life of 10 years.

| **Project A** | **Yield % p.a.** | **Probability** | **Cumulative Prob.** |
|---|---|---|---|
| | -5 | 0.5 | 0.5 |
| | 10 | 0.5 | **1.0** |
| **Project B** | 2 | 0.1 | 0.1 |
| | 5 | 0.4 | 0.5 |
| | 8 | 0.3 | 0.8 |
| | 12 | 0.2 | **1.0** |
| **Project C** | 5 | 0.2 | 0.2 |
| | 9 | 0.4 | 0.6 |
| | 12 | 0.3 | 0.9 |
| | 18 | 0.1 | **1.0** |

**Simulate the total results from the five projects during the first five years of their life.**

| | Project A | | | Project B | Project C | Total |
|---|---|---|---|---|---|---|
| Year | R. No. | Yield | Profit | | | |
| 1 | 48 | -5 | -1,000 | | | |
| 2 | 36 | -5 | -1,000 | | | |
| 3 | 75 | 10 | 2,000 | | | |
| 4 | 66 | 10 | 2,000 | | | |
| 5 | 26 | -5 | -1,000 | | | |

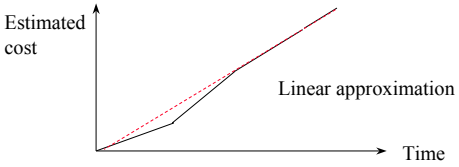
In a similar fashion to Project A, assess the other 4 projects and get the total for each year.

The S-curve is valuable for the purpose of estimating the amount of working capital required for a project.

**Hammock Activity "overheads + supervision"**

It starts and finishes at the events which mark the span of the activities to which the indirect costs refer.

A lump sum uniformly spread over the duration (rate per day)




Pattern of expenditure for workpackage

# COST MANAGEMENT

# CONTRACTORS PERSPECTIVE

Dr Rodney Stewart

## The Contractor's Perspective

**Working Capital**

**is the requirement for Cash to finance work from day-to-day**

Essentially, it is the difference between **expenditure and receipts**

- Cash
- Materials (raw or incorporated in work in progress )
- Current accounts receivable

**Working Capital** is required for:
short-term commitments: salaries and wages, buying materials, repair of equipment.
Accurate and detailed consideration of **Working Capital** can be of particular concern.

Work can be formed. only if funds are available.

The timing of cash ***inflow*** and cash ***outflow*** is critical

There will be a ***time lag*** between being committed to making a payment and actually making it.

There is also a ***time lag*** between the entitlement to receive cash and actually receiving it.

Such ***time lags*** have a considerable effect on the financial status of the organisation.

Cash has to be available when payments to **creditors** fall due.

Lack of available funds precludes a company from procuring new jobs.

**Example:** To distinguish between cash flow differences, this contractor builds residential units for $60,000 and sells them for $80,000. Investigate a number of different credit arrangements

| Credit Arrangement | Funds req. from outside | Funds available at the end |
|---|---|---|
| Build 10 for cash & sell 10 for cash | ---------- | $800,000 |
| Build 10 on credit & sell 10 for cash | $600,000 | $200,000 |
| Build 10 for cash & sell 10 for credit | ---------- | ---------- |

**Example:** Assume that the turnover for the current year is $1,000,000.

Speculate on fluctuations (detailed changes) within this year?

The principle is to calculate/estimate the **cash receipts** together with **the payments** which are **outstanding**.

Assume that clients are allowed 8 weeks' credit. This means that at any one time, an average of (8/52) * 1,000,000 = **$154,000** owed to the company by the clients.

As the company delivers to the client, a **debtor** is created.
**A debtor is discharged when he client pays for the work (goods).**

In addition to debtors, the firm may pay insurance, tax, rent, etc. **in advance** "pre-payments". assume **$6,000**

**Stock: raw materials** and **work-in-progress**;
assume 35% of the turnover is in **raw materials** and
8 weeks' consumption needs to be in hand at any one time.

So 0.35 (1,000,000) (8/52) = **$54,000**

**Work-in-progress (all that work carried out but for which the owner has as yet not reimbursed the contractor)**

is estimated by 6 weeks' turnover
(6/52) (1,000,000) = **$115,000**

The total firm's capital "tied-up" = 115+54+ 6 + 154 = $329,000

**Creditors: the company owes money to suppliers and must pay**
say the company is allowed an average of **10 weeks**.
Creditors will be owed (10/52) (1,000,000) = **$192,000**

| | | |
|---|---|---|
| Debtors | $ 154,000 | |
| Prepayments | $ 6,000 | |
| Raw materials | $ 54,000 | The contractor actually paid |
| Work in progress | $ 115,000 | this amount of money to carry |
| Total | $ 329,000 | out the work. |

**Deduct**

| | | |
|---|---|---|
| Creditors | $ 192,000 | |
| Accruals (bills) | $ 10,000 | The contractor has to pay this |
| Total | $ 202,000 | money. |

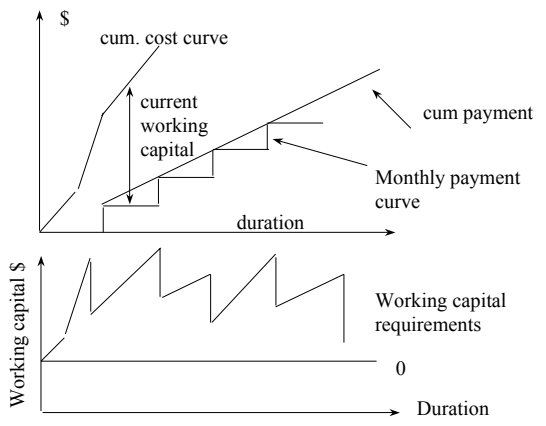
Working capital required in this accounting period =
329,000 – 202,000 = $127,000

The length of time over which credit is allowed and received can cause wide **fluctuations** in the requirement for **Working Capital**.

In the event that sufficient cash is not available as and when required, then:

1. Finance can be obtained from external sources
2. reduce work-in-progress
3. speed-up claims for payments as work is completed.

| Month end | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Cumulative cost (1) | 0 | 48 | 160 | 270 | 355 | 420 |
| Cum. value (contract) | 0 | 52 | 172 | 290 | 382 | 450 |
| Cum. paid (3) | 0 | 0 | 49 | 160 | 275 | 360 |
| Working Capital (1-3) | 0 | 48 | 111 | 110 | 80 | 60 |
| Cum. retention | 0 | 0 | 3 | 12 | 15 | 22 |



## Profit and profitability

Profit is what is left from what is received as a result of carrying out the work after paying all the charges that arise out of a project.

Profit/loss gives **no measure** of the productivity or efficiency of operations.

Profitability is a rate of **making profit in relation to a company's investment** that is required to carry out the work.

**Factors to determine profitability:**
1. Investment
2. Profit (amount), and
3. Project duration.

A contractor makes $5,000 profit on one contract and $6000 on a second. Contract 1 and 2 require an investment of $10,000 and $8,000 respectively. If the contracts have different duration say 1 year and 18 months respectively, compare the profitability.

**INVESTMENT**

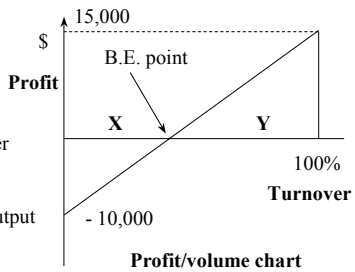
It is the **use of a cumulative S-curve of actual cost against which is plotted the income curve in a stepped form**.

Total investment required to finance a project over its duration is represented **by the area between the curves**.

Each project must make a contribution towards the indirect cost. (office overheads for example).

**Turnover = Fixed cost + Variable cost + Profit**

**Simple tools to measure profit**




**Profit/volume chart**

100% output has a turnover of $100,000

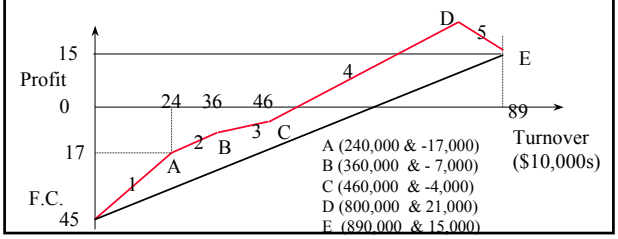
fixed costs at this 100% output amount to $10,000

Variable costs amount to $75,000

X/Y = 10/15 leads to a break-even point at 33.33%

| Contract | Value completed ($) | Contribution to date ($) |
|---|---|---|
| 1 | 240,000 | 28,000 |
| 2 | 120,000 | 10,000 |
| 3 | 100,000 | 3,000 |
| 4 | 340,000 | 25,000 |
| 5 | 90,000 | - 6,000 |
| Total | 890,000 | 60,000 |

**Fixed costs for the period concerned amount to $45,000**




**Example:**
The managing director requires an annual return of 17% on the $20,000,000 capital employed in the company.
Of this capital, $13,000,000 is invested in **fixed assets** and the remainder is available as **working capital** to finance all contracts in progress.
In the coming year, it is estimated that the turnover on contracts will be $40,000,000.
What percentage must be added to contract costs for the year of mark-up if the company's overheads are expected to amount to $1,600,000?

**Solution:**

The work on contracts must contribute $1,600,000 for the company's overheads **PLUS** 17% on the $20,000,000 for the return required.

This makes a total of $5,000,000 = 71.4% of the working capital

It is necessary, therefore, to aim at an average annual return on investment of nearly 72% to meet the target.

As a percentage of the turnover, the contribution amounts to 5,000,000 / 40,000,000 = 12.5%

You need to add 12.5% to contracts in order to generate the required contribution.

**Note: Management should be concerned with**

1. Minimising the area between the S-curve of actual cost and the curve of payments received (delay outgoing payment for example)

2. Every contract must make an average contribution to the company's overheads.

## Return on a construction project

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| End of month | Expenditure ($1,000s) | Revenue ($1,000) | Net cash flow | Cum. net cash flow ($1,000) |
| 1 | 40 | 0 | -40 | -40 |
| 2 | 45 | 75 | 30 | -10 |
| 3 | 78 | 72 | - 6 | -16 |
| 4 | 95 | 81 | -14 | -30 |
| 5 | 120 | 108 | -12 | -42 |
| 6 | 162 | 160 | - 2 | **-44** |
| ... | | | | |
| 11 | 0 | 65 | 65 | **72** |
| **Totals** | 720 | 792 | **72** | |

**The question now is how does the contractor finance the project?**

(1) the contractor's equity / shareholder's funds or
(2) borrowing (interest charges)

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| End of month | Net cash flow | Cum. net cash flow ($1,000) | Interest at 1% month | Net cash flow |
| 1 | -40 | -40 | 0.0 | -40.0 |
| 2 | 30 | -10 | -0.4 | 29.6 |
| 3 | - 6 | -16 | -0.1 | -6.10 |
| 4 | -14 | -30 | -0.16 | -14.16 |
| 5 | -12 | -42 | -0.3 | -12.30 |
| 6 | - 2 | **-44** | | |
| ... | | | | |
| 11 | 72 | | -2.76 | **69.24** |

**ANNUAL BUDGET**

**1996 (anticipated receipts $000)**

| Contract | J | F | M | A..... | D | Totals |
|---|---|---|---|---|---|---|
| A | 100 | 250 | 300 | 400 | -- | 2000 |
| B | 600 | 600 | 400 | 200 | -- | 3000 |
| C | 100 | 100 | 100 | 150 | 600 | 3500 |
| Totals | 800 | 950 | 800 | 750 | 600 | 8500 |

Of the above totals:

(a) Direct costs = 6,970,000 (82%)
(b) Overheads = 680,000 (8%)
(c) Profit = 850,000 (10%)

Company financial budget: The total value of work to be carried out amounts to $8,500,000

## Price Changes

The adjustment to the value of money and to cost/price data generally is best carried out by the use of **an INDEX**.
There are **2 approaches** to the development of a cost/price index

1. A simple model that uses historical prices for a unit quantity of a well-defined product. (easy to understand). (***an average price for a cubic metre of excavation***).

2. This approach requires a supply of data and reflects the relative quantities of resources that are required to produce a unit. (***production: factors such as labour, plant, transportation,etc.***)

At the time of tendering, a contractor has no alternative but to use the **current price** levels for the resources. Some may, however, add an allowance for future changing levels of prices.

**Example:**
A contractor estimates the cost of a project to be **$100,000** at current prices. The contractor adds a profit margin of **15%** on which he expects to pay tax at a rate of **50%**.
If inflation is running at **1% per month** and the owner fully compensates the contractor for price increases due to inflation but delays payment **until 1 month** after certification, what is the contractor's true profit margin after tax?

**Solution:** let P = profit, C = estimated cost
So, profit margin (m) = P / C

assuming (t) is tax rate then,

Profit (P) = (1+m) C – C  Profit (less tax) = (1+m) C – C – tmC
If inflation was zero,
then Effective Profit margin = (1+0.15) – 1 – 0.5(0.15) = 7.5%

If the owner fully compensates the contractor for an inflation rate of 1% per month, the contractor's profit after tax becomes:

$$\frac{(1+0.15)}{(1+0.01)} - 1 - 0.5\,(0.15) = 6.36\,\%$$

## VARIANCES AND STANDARD COSTS

Making arrangements to collect project cost data is one thing, processing this data into information is quite another.

It is necessary to have some form of **standard** against which the actual cost can be measured.

Any departure from the set standard in practice is known as a ***Variance*** **Favourable variance (savings)**

## Standard costs

Predetermined costs of material, labour and overheads which are budgeted to be spent in the production of a unit in the immediate future.

A variance between the standard and the actual cost can **only occur** if:

(1) more or less resources are used to achieve the required output.

(2) more or less money has to be paid for the anticipated resources.

What we are looking for? ***QUANTITY OF RESOURCES & PRICES***

**ADVANTAGES OF THIS SYSTEM:**

It enables the variances to be calculated and analysed in monetary terms, this leads to the exposure of inefficiencies.

## Material Variances:

**Example:**
At the time of tendering, **13.29** tonnes of mild steel reinforcing bar were required. The average cost of the various sizes of bar, by quotation, came to **$440 per tonne** delivered to site.
The weight included the company's usual allowances for wastage.

When the reinforcement had been cut, bent and fixed in position, a check of the stock showed that **13.97 tonnes** had been used for this work and that the actual weighted average cost of the material came to **$432** per tonne.

Standard price = $440/tonne Standard quantity = 13.29 tonnes
**Standard cost** = 13.29 (440) = **$5847.60**
Actual price = $432/tonne Actual quantity = 13.97 tonnes
**Actual cost** = 13.97 (432) = **$6035.05**
**Material cost variance** = 5847.6 – 6035.05 = $187.45 **(unfavourable)**

## Labour Variances:

**Example:**

The all-in rate for carpenters is calculated at **$15/hour**. A work study establishes that the carpenters should take **520 hours** to do the job. In fact it took them **502 hours** and their actual rate is calculated at **$15.50/hour**. Calculate the relevant labour variance**(s)**.

Labour rate variance = 502 (15.0-15.5) = $251 (unfavourable)

Labour efficiency variance = 15.0 (520-502) = $270 (favourable)

Labour cost variance = 270 - 251 = $19 (favourable)
OR
Labour cost variance = 15(520) - 15.5 (502) = 19 (favourable)

## Overhead Variances:

**Example:**
The overhead budget for a project contains **$120,000** for fixed costs and **$48,000** for variable costs. The contract has been based on a duration of **280 working days**.
In reviewing the work at the outset it was assessed that one self-contained section of the project should be allowed **170 working days** for completion. In fact it took **181 days** and an overhead of **$115,000** was incurred.
***Calculate*** the overhead variance**s** for the section of the project completed

**Solution:**

Section budget for fixed costs = 120,000 (170/280) = $72,857
Section budget for variable costs = 48,000(170/280) = $29,143
Total overhead budget cost for section = $102, 000

Standard days are allowed for section = 170 days
Standard fixed overhead/day = $72,857/170 = $428.57
Standard variable overhead/day = $29,143 /170 = $171.43
Standard total overhead/day = $600.00
Standard overhead for section = 170 (600) = $102,000

Actual duration taken = 181 days
Actual overhead incurred = $115,000

**Overhead variance** = 102,000 - 115,000 = $13,000 (unfavourable.)

This overhead variance may be analysed into three sub-variances:
**(1) Overhead efficiency variance** = standard cost of standard units – standard cost of actual nits

Overhead efficiency variance = 600 (170–181) = $6600 (unfavour.)

**(2) Overhead cost variance =** budgeted overhead for actual units worked – actual overhead incurred

**Overhead cost variance** = 103,886 - 115,000 = $ 11,114 (unfavoured.)

**(3) The overhead volume variance** = standard cost of actual units – flexible budget for actual units

Flexible overhead for actual duration taken =
72,857 + 181 (171.43) = $103,886

**Overhead volume variance** = 181 (600) – 103,886= $4,714 (favourable)

If you add (1), (2) and (3)

– 6,600 – 11,114 + 4,714 = $13000 (overhead variance)

## Overhead Variances:

**Variable overheads** cost vary directly with the rate of production

**Fixed overheads** cost do not vary with the rate of production
Unchanged whether work is progressing or not (eg. site offices)

The overhead budget has two components:

(1) fixed component (fairly spread over over a period of time)

(2) variable (flexible) component (needs to be changed in relation to varying levels of activity.

The idea is to differentiate between the budgeted (standard) and actual expenditure.

**Going back to the example:**

Based on our estimation that it will take 170 days to complete the section, then the overhead cost associated with this section has two parts:

Part 1 $72,857 (fixed) = $428.57/day (its share in the contract).

Part 2 $29,143 (variable) = $171.43/day

Total overhead budget for the section (standard) =

72,857 + 29,143 = $102,000

Therefore, overhead variance = 102,000 - 115,000 = $13,000 (unfav.)

This overhead variance can be analysed as follows:

Overhead efficiency variance:

How efficient was the contractor in carrying out the work?

It took him 11 days longer than anticipated, then

**Overhead efficiency variance** = 11 (600) = $6600 (unfavourable)

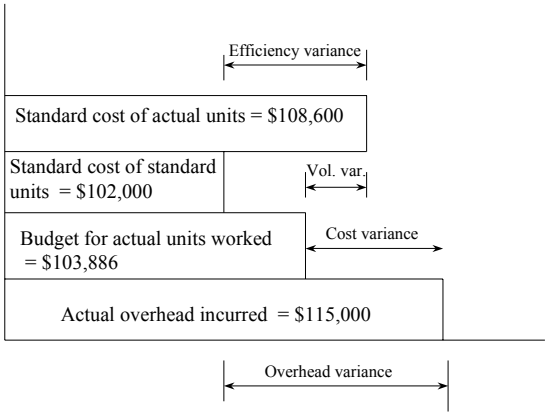
Overhead cost variance:

regardless of how long it took to complete the section, $72,857 is incurred as fixed cost, then the budget for the section =
72,857 + 181(171.43) = $103,886 or
102,000 + 11(171,43) = $103,886
**Overhead cost variance** = 103,886 - 115,000 = $11,114 (unfavour.)

Finally, the **overhead volume variance** represents the difference between the budgeted and actual output In the budget if I had worked 181 days, I would have simply paid 181 (600) = $108,600

but budgeted payment for actual work was only $103,886
So **overhead volume variance** is favourable $4,714

**In summary,** my budget implies overhead cost = $600 /day
**(1)** I worked 11 days more to finish the job therefore my **overhead efficiency factor** is 11(600) = $6600 (unfavourable)
**(2)** I actually paid $115,000 for what I should have paid (not just according to the budget, but according to the actual duration)
102,000 + 11(171.43) = $103,886
**cost efficiency factor** is 103,886 - 115,000 = $11,114 (unfavourable)
**(3)** According to my budget I should have paid 181(600) = $108,600 but the budgeted payment for actual work = $103,886
**overhead volume variance** is favourable $4,714 (favourable)



# REVISION LECTURE

Dr Rodney Stewart

## Construction Resource Planning Revision

**Topics Covered**:

**1. Networks**:
- •PDM Networks (ES, EF, LS, LF, FF, TF)
- •Activity on Arrow Networks
- •SS, FS, FF relationships
- •PERT networks
- •Resource Levelling
- •Crashing Networks

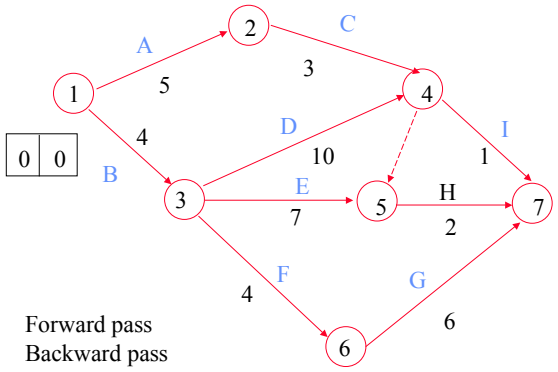
**2. Line of Balance – Know equations**
**3. Queuing Theory – Know equations**
**4. Simulation – ie. random numbers etc.**
**5. Stock Control – Know equations**
**6. Resource Allocation – Matrix reduction**

**Topics Covered (cont.)**:

**7. Equipment Planning**
**8. Decision-making under uncertainty** (opportunity-loss tables, EMV, EVPI)
**9. Cost Planning** (Turnover, BEP, Profit, overheads etc.)
**10. Cost Planning – Contractors perspective**
- • Variance
- • Price changes
- • Working Capital

# NETWORKS

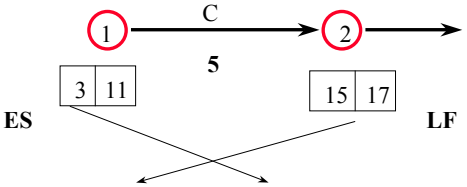
## Activity on Arrow (Please Try)




Forward pass
Backward pass

## Activity on Arrow

### Rules for Calculating Float

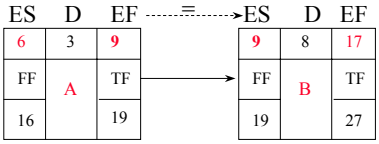



**TF = 17 — 3 — 5 = 9**

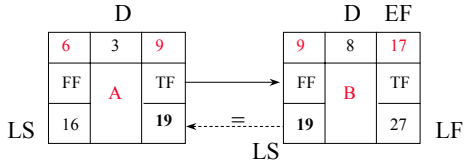
**FF = 15 — 3 — 5 = 7**

## Precedence Diagram Method (PDM)

# Forward Pass

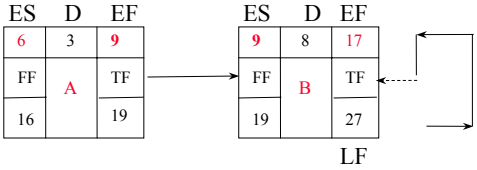



# Backward Pass

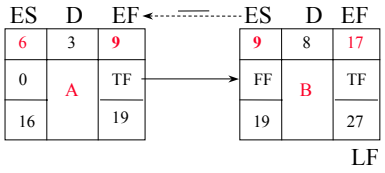


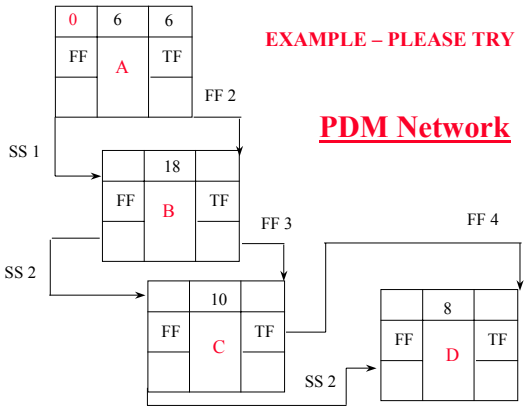

## Precedence Diagram Method (PDM)

# Total Float



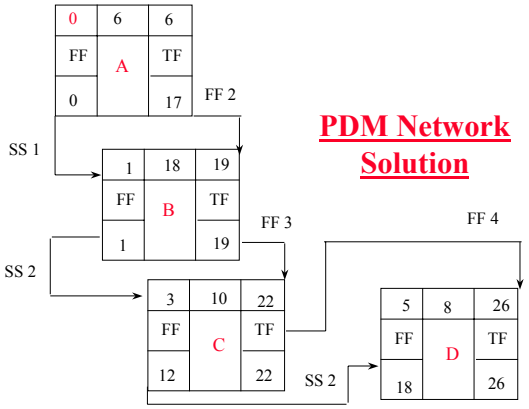

# Free Float




**EXAMPLE – PLEASE TRY**

## PDM Network

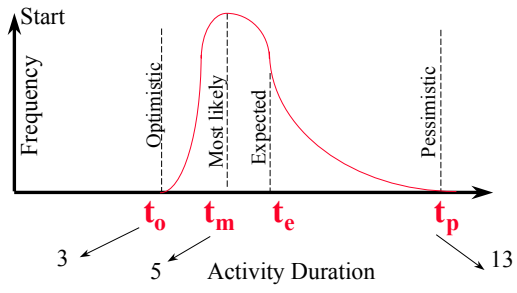



## PDM Network Solution

# PERT NETWORKS

Why do we need PERT?
Deterministic vs. Probabilistic duration
Variability in estimating duration or
Probability of meeting the target

PERT allows for
**Optimistic**
**Most likely and**
**Pessimistic values**
**to be considered in predicting the overall time**




**Continuous Probability Distribution**

**Expected time** $t_e = [\, t_o + 4t_m + t_p \,] \;/\; 6$

**Standard Deviation** $S = (\, t_x - t_e \,) \;/\; 6$

## Steps for PERT

1. Estimate to, tm, tp for each activity (given values)
2. Compute te for each activity (use te equation)
3. Calculate standard deviation for each activity

$$S = ( tp - to ) / 6$$

4. Calculate variance for each activity

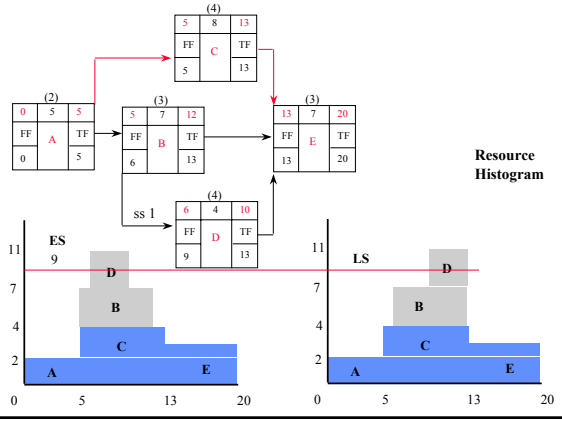
$$V = S*S$$

5. Determine ES, EF, LS, LF, TF, FF
6. Determine Te (Critical Path) = $\Sigma$ te along C.P.
7. What is the confidence in calculated Te

   $V(te) = \Sigma V$ for ***critical activities only***

   and project standard deviation $S(te) = \sqrt{V(te)}$
8. Use probability tables to compute your chance in meeting the target duration

## RESOURCE HANDLING

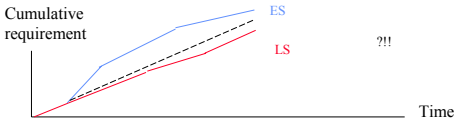



In practice, there might be **too many** options.
It all depends on your perspective and priorities.
Once you compared supply to demand, investigate ways of levelling/smoothing the demand profile

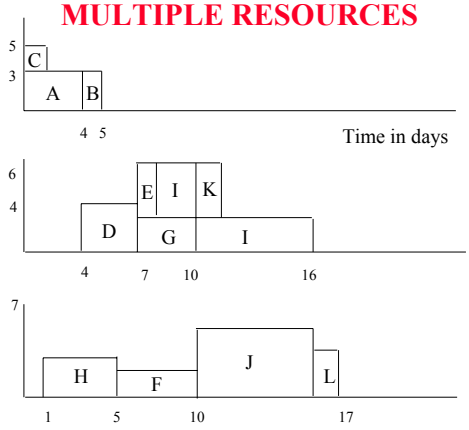
- Use of free float on activities demanding that resource
- Use of total float
- Use of flexible resources to stretch activity duration
- Extend the project total time (last resort, if no penalty is involved)

The ideal histogram is that with as few changes in level as possible

Remove the *peaks* and Raise the *valleys*



# MULTIPLE RESOURCES

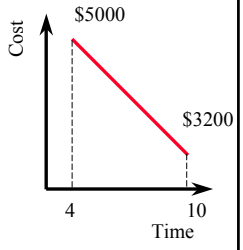



# CRASHING NETWORKS

**The objective of each stage in crashing a schedule is to work on *one* (or more) activities to produce a feasible *shorter schedule* for the *minimum increased direct cost per unit*.**

Steps:

1. List all activities on the critical path
2. Select the activity with potential (time savings for least cost: low slope)
3. Determine new critical path(s) if any
4. Re-evaluate the network
5. Repeat the above for another activity.




cost slope= $300/day

# LINE OF BALANCE (LOB)

LOB is a graphic technique used to :

- Plan the production of repetitive operations.
- Examine the implications of using given resource configurations for such operations.

**Applications:**

Repetitive construction work (over and over) (multi-storey building, pipelines, road construction)

**Conditions:**

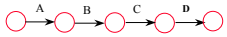
Direct control on repetitive activities

**Aim:**

Provide regular/balanced delivery of the product based upon continuous use of resources.

The first step is to **prepare your logic diagram**
then, **estimate the resource units** (eg manhours) to complete each activity. Using the above, **determine actual production rate**

Construct: **106 units**
5 working days@ 7hr/day = **35hrs/week**
Target Rate R = **8 units per week.**



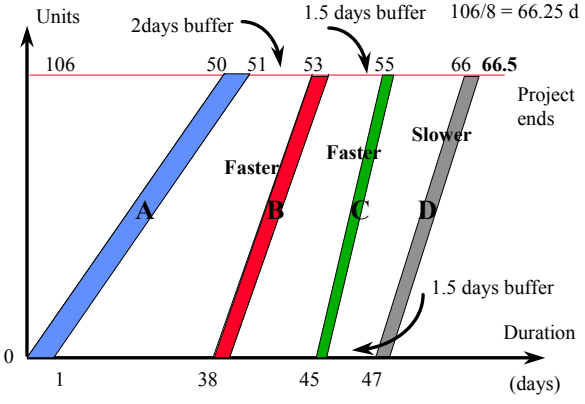

| Act. ID | Manhours req'd | Gang size | Theoretical gang size for Rate R | Actual gang size | Actual rate of output (units/week) |
|---|---|---|---|---|---|
| A | 20 | 3 | 8*20/35 = 4.6 | 6 | (6/4.6)*8 =10.5 |
| B | 2 | 2 | 8*2/35 =0.46 | 2 | (2/0.46)*8 = 35 |
| C | 2 | 3 | 8*2/35 =0.46 | 3 | (3/0.46)*8 = 52.5 |
| D | 5 | 4 | 8*5/35 =1.14 | 4 | (4/1.14)*8 = 28 |

The second step is to **determine time required to complete 1 unit** and the elapse time per activity (the start of last unit - the start of 1st) Using these values, **represent each activity graphically**

7 Hours per day

| Act. ID | Actual rate of output (units/week) | Time per activity (days) | Elapsed time bet. start on 1st unit and last unit (days) |
|---|---|---|---|
| A | 10.5 | 20/(3*7) = 0.95 | (105*5)/10.5 = 50 |
| B | 35 | 2/(2*7) = 0.14 | (105*5)/35 = 15 |
| C | 52.5 | 2/(3*7) = 0.10 | (105*5)/52.5 = 10 |
| D | 28 | 5/(4*7) = 0.18 | (105*5)/28 = 19 |

Manhours required
round them off to multiple 0.5 days
5 Days per weeks
(106-1)
Theoretical Gang Size



# QUEUING EQUATIONS

$\lambda$ mean arrival rate
$\mu$ mean rate of service $\mu > \lambda$

The Traffic Intensity $\rho = \lambda / \mu$

**Equations:**

The number of units in the system; $N = \frac{\lambda}{\mu - \lambda}$ **(1)**

2 trucks arriving per hr
3 trucks serviced per hr

then N = 2/(3-2) = 2 trucks in the system on the average

The average time a unit spends in the system; $T = 1 / (\mu - \lambda)$ **(2)**

T = 1 (3-2) = 1 hr

The average number of units in the queue; $Nq = \frac{\lambda^2}{\mu(\mu - \lambda)}$ **(3)**

Nq = 2*2 / 3(3-2) = 1.33 trucks on average

The average time a units spends in the queue $Tq = \frac{\lambda}{\mu(\mu - \lambda)}$ **(4)**

Tq = 2/ 3(3-2) = 40 minutes

The utilisation factor $\rho = \lambda / \mu$ 67% of time server is busy

Probability of having no trucks in the system = 33%

## Problem (Please Try):

Material arrives at the average rate of five (5) loads per hour. The material is handled by a fork-lift truck which has an average rate of seven (7) loads per hour.

**Management requires to know:**

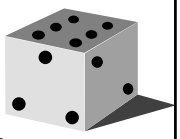
a) the average number of loads at the section waiting to be moved, when there is a queue
b) the average length of time an arriving load spends waiting for service
c) what the average service-rate must be in order to reduce the expected waiting time to 15 minutes for a load.

# SIMULATION

When a system contains elements that **exhibit chance** in their behaviour, the *Monte Carlo* method of simulation may be applied. "experimentation on the chance elements through random sampling".

**Simulating randomness**

Each digit has probability 16.6% of occurrence



**Establishing a probability distribution "historical data"**

| Calls for your flatmate | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Frequency (days) | 10 | 20 | 40 | 60 | 40 | 30 |
| Prob. of occurrence % | 5 | 10 | 20 | 30 | 20 | 10 |

**Example of Monte Carlo Simulation**

Concrete trucks arriving at a site requiring 20 concrete trucks
It takes about 3 minutes to discharge a truck (2 trucks max. in a queue)

| Arrival time intervals(min) | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Frequency % | 10 | 15 | 30 | 25 | 20 |
| Interval of R. Number | 0-9 | 10-24 | 25-54 | 55-79 | 80-99 |

| Truck No. | 1 | 2 | 3 | 4 | | 11 | 12 |
|---|---|---|---|---|---|---|---|
| R. No. | 89 | 29 | 73 | 50 | | 88 | 2 |
| Arr. time | 6 | 4 | 5 | 4 | | 6 | 2 |
| Cum. time | 6 | 10 | 15 | 23 | | 48 | 50 |

# STOCK CONTROL DECISION

How much to order? When to order?

Cost of the items **Cost of ordering "delivery"** **Cost of holding**
Cost of safety stock Cost of stockouts

| **Cost of ordering** | **Cost of holding** |
|---|---|
| Processing Purchasing order | Cost of capital |
| Inspecting incoming material | Insurance |
| Bill paying | Theft |
| Utilities (phone bills) | Damage |
| Purchasing dept. employees | Warehouse employees |

## How much to order?

**BASIC STOCK CONTROL MODEL** Stock level

**Q Order Quantity**

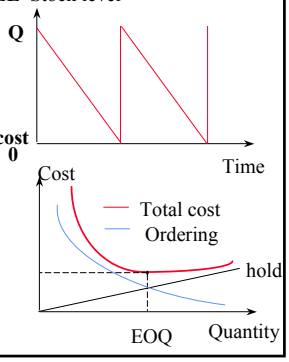
**EOQ Economic Order Quantity**

**Total cost = ordering cost + holding cost**

**Annual ordering cost = cd/Q**

**Annual holding cost = (ip) Q/2**

$$Q = \sqrt{\frac{2cd}{ip}}$$




## Example (please try)

Annual demand is 40,000 units, ordering cost = $15 per order
holding cost is $3 per unit per year
If there are 160 working days per year, find the daily demand
and the optimal number of days between orders?

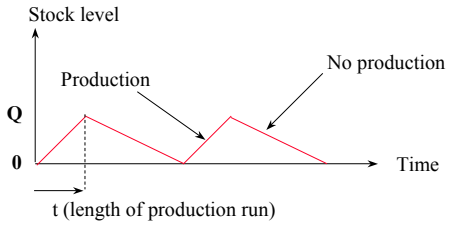
**Solution** d = 40,000 c = $15 ip = $3

So optimal Q = 632 units

$$= \sqrt{\frac{2cd}{ip}}$$

Optimal no. of orders per years = 40,000/632 = 63.3 = 64
Daily demand = 40,000 / 160 = 250 units
Optimal no. of days between orders = 160/ 64 = 2.5 working days

# STOCK LEVEL AS A FUNCTION OF TIME




- The batch will not arrive all at once but is built up at uniform rate.
- Stock refers to **products**.
- As soon as stock runs out, the producer immediately embarks on production of new batch. While production of this batch is still going on, items made earlier can be sold.
- We will have a set-up cost (cost for setting-up production).

Therefore,
total produced – total used $= rt - dt = (r - d)\,t$
$= (r - d)(Q / r)$
$= Q(1 - d/r)$

**Annual holding costs = 0.5 Q (1 – d/r) (ip)** **(2)**

## **Remember** – these equations are different

| Production Run Model | Basic Stock Control Model |
|---|---|
| $Q = \sqrt{\frac{2cd}{ip\,(1-d/r)}}$ | $Q = \sqrt{\frac{2cd}{ip}}$ |

**d** **selling rate**
**r** **production rate**

# MATRIX REDUCTION

What do we need is an a method that can provide us with efficient means of finding the **OPTIMAL** solution without having to make a direct comparison of every option.

(1) **Create a matrix of opportunity cost**.

Subtract the smallest no. in **each row** of the original cost matrix from every number in that **row**, and THEN

Subtract the smallest number in **each column** of matrix obtained from every number in that **column**.

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | $11 | $14 | **$6** |
| BROWN | **$8** | $10 | $11 |
| COOPER | $9 | $12 | **$7** |

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | 5 | 8 | 0 |
| BROWN | 0 | **2** | 3 |
| COOPER | 2 | 5 | 0 |

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | 5 | 6 | 0 |
| BROWN | 0 | 0 | 3 |
| COOPER | 2 | 3 | 0 |

(2) Connect "zeros" either vertically or horizontally and then compare the no. of lines (N), we are after the minimum number of straight lines needed to cover ALL "zeros".
If (N) = number of rows/columns Optimal solution

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | 5 | 6 | 0 |
| BROWN | 0 | 0 | 3 |
| COOPER | **2** | 3 | 0 |

(3) Subtract the smallest number "not covered" from **EVERY** other uncovered number and then add the same number to the intersection of any 2 lines even if it was (0).

| | T1 | T2 | T3 |
|---|---|---|---|
| ADAMS | 3 | 4 | **0** |
| BROWN | 0 | **0** | 5 |
| COOPER | **0** | 1 | 0 |

You can have an optimal solution by **Maximising efficiency**

**Example (Please Try):**
The only difference is that you need to convert the matrix first into a minimising opportunity cost table and then proceed with the previous three steps as before.

| | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| ADAMS | 20 | 60 | 50 | 55 |
| BROWN | 60 | 30 | 80 | 75 |
| COOPER | 80 | **100** | 90 | 80 |
| DAVIS | 65 | 80 | 75 | 70 |

| | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| ADAMS | 80 | **40** | 50 | 45 |
| BROWN | 40 | 70 | **20** | 25 |
| COOPER | 20 | **0** | 10 | 20 |
| DAVIS | 35 | **20** | 25 | 30 |

## EQUIPMENT PLANNING

**You need to buy an equipment**

| Age at Purchase | Price (k) | Age of machine | Resale (k) | Maintenance (k) |
|---|---|---|---|---|
| 0 | 40 | | | |
| 1 | 31 | 1 | 28 | 3 |
| 2 | 20 | 2 | 18 | 4 |
| 3 | 11 | 3 | 10 | 6 |
| | | 4 | 4 | 9 |

Determine what age of machine should be purchased and when it should be replaced.

## DECISION MAKING

### D.M. under Risk

| | Boom | Recession |
|---|---|---|
| Buy a large-capacity machine | 200,000 | –180,000 |
| Buy a small-capacity machine | 100,000 | – 20,000 |
| Buy nothing | 0 | 0 |

This is highly dependent on the probability of having a recession, say it is 50/50 for this example

- **Expected Monetary Value** (EMV)
- Select the option with the **maximum (EMV)**
- **Opportunity Loss Table**
- **Expected Opportunity Loss**
- **EVPI = EP – Max. EMV (EP = expected value with perfect information)**

## COST FUNDAMENTALS

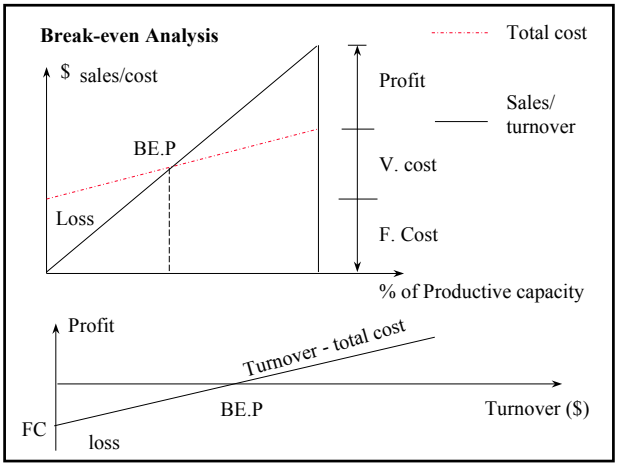
**Production Cost**

A combination of Factors of Production
Calculating cost on the basis of combining these factors.

Fixed, Variable and Semi-variable Costs

**Equipment**

**Fixed costs** tend to be unaffected by the amount of work
**Variable costs** incurred in proportion to the amount of work
**Semi-variable costs** "difficult to be predetermined with precision".




## The Contractor's Perspective

**Working Capital**

**is the requirement for Cash to finance work from day-to-day**

Essentially, it is the difference between **expenditure and receipts**

- Cash
- Materials (raw or incorporated in work in progress )
- Current accounts receivable

**Working Capital** is required for:
short-term commitments: salaries and wages, buying materials, repair of equipment.
**Variance**: Material, overhead, staff etc.

# Thankyou

## Exam

**Study All Tutorials and Final Exams**
**Good Luck**

## Subject Evaluation

**Please fill out a subject evaluation**
**All recommendations appreciated**

# 7056ENG

Resource Planning and Management

# Readings:
# Topics 1-9 (in order)

Dr Rodney Stewart

# Reading

Lockyer, K. and Gordon, J. (1996) *Project Management and Project Network Techniques*, 6th Edition, Pitman Publishing, pp. 21-34.

CHAPTER 4

# Planning the project

Any endeavour should be planned and, the larger or more complex or uncertain it is, the more essential a plan becomes. This is particularly true of projects because of their uniqueness and, except for very small projects, the planning activity needs to be formalised. Even small projects can be complex and require careful planning to resolve the interactions between the various jobs or activities which make up the work in the project.

## OUTLINE OF PLANNING CONCEPTS

Present decisions affect both present and *future* actions and, if immediate, short-term decisions are not made within the framework of long-term plans, then the short-term decisions may effectively impose some long-term actions which are undesirable but inescapable. Military writers categorise these long- and short-term plans as:

- *strategic plans* – which are those made to 'serve the needs of generalship'
- *tactical plans* – which are those made 'when in contact with the enemy'.

Ideally, of course, strategic plans are made before the start of an operation and, by following them, the operation is successfully concluded. Inevitably, however, tactical decisions will have to be made and these can only be successful if they are made within the context of the strategic plan.

To permit effective tactical decision making, it is necessary for the strategy to be expressed in a form that is:

- explicit
- intelligible
- capable of accepting change
- capable of being monitored.

It must be realised that there is no absolute definition of strategy and tactics: at any one level in a hierarchy a tactical plan should be made to fit the needs of the strategy received from a higher level and this tactical plan then becomes the strategy for a lower level. Freedom to make appropriate decisions must be given to those who will be held responsible for performance and, if these decisions are to be meaningful in a larger context, then

it is imperative that this larger context be known. Freedom 'within the law' is as important a concept in management as in the community. Too often tactical decisions are taken to meet the needs of immediate expediency, and the results may well be disastrous in the long term.

## OPPORTUNITY COSTS

In planning, as indeed in project control, a valuable concept for the project manager is that of *opportunity cost*:

> **Opportunity cost – that which is sacrificed by choosing or failing to adopt a different course of action to that which is currently planned to be taken.**

Probably the simplest example to illustrate the concept is to consider a person with £1000 in cash. For safety this is put in a box hidden under the bed. At the end of a year the £1000 is unchanged. However, it could have been placed in an equally safe investment with an annual return of 10 per cent. What has been lost – sacrificed – is £100, so the opportunity cost of the 'box under the bed' policy is therefore £100.

This concept can be widely applied. Thus, for example, at a project milestone it is forecast that the project will overrun by one week and the penalty clause states that for each week of overrun a penalty of £1000 will be levied. The opportunity cost of not taking any corrective action to pull the project back by one week is £1000, and this will give an idea of the extra cost which can be economically incurred to avoid the overrun.

A second example concerns procurement. Suppose a piece of capital equipment is to be hired for use on the project at a weekly rate of £1000. It is brought onto site three weeks before it is needed. The opportunity cost of this early hiring is £3000 plus any financing charges and the weekly cost of storage and insurance. Equally, material which is over-ordered or delivered early will attract an opportunity cost which is often alarmingly high.

It should be noted that opportunity costs do not show up in the final project accounts, being absorbed in the general financing. Thus, in the example above of the piece of equipment brought on site early, the hiring cost will appear as one item. A declaration of the extra costs involved by bringing the equipment on site before it was needed is a statement which is outside the experience of either author. It is also true that opportunity cost may not be the sole criterion in making a decision. It may be that other commercial considerations outweigh the opportunity cost but it must always be taken into account.



## ELEMENTS OF PROJECT PLANNING

The earliest attempt at a formal planning system was the *Gantt chart* which was derived from the simple *bar chart*. The use of the term 'bar chart' is now so universal for referring to either form that it has been used throughout this text, except in this chapter where 'Gantt charts' and 'bar charts' are discussed.

A project plan in its simplest form is an attempt at a timetable for all the activities which make up the project. It forms the first major step in the project management process, and sets out 'how', 'who does what' and 'when'. At the next stage of sophistication it will also state to 'what level of performance and quality' and at 'what cost'. At a yet higher stage of sophistication it will also be related to the availability of the resources required to carry out the activities. As each stage is considered, it may be necessary to reconsider and modify the preceding ones.

The process of creating a project plan is the responsibility of the project manager and the project team, with the advice and assistance of the project sponsor, the customer and other stakeholders. The preparation of a project plan is an iterative process. It needs to be reviewed and updated as information becomes available throughout the life of the project. It is never a static document and it forms the base against which all progress in the project is measured. It must therefore be as accurate and up-to-date as is possible. *No plan should ever be regarded as set in concrete – it is a working tool.*

There will always be several levels within the project plan. At the highest level it will be a summary showing key events and milestones in the project as an executive overview for senior management. In a consortium project, the plan will indicate the agreed division of work between the members of the consortium. The lower levels will have increasing amounts of detail with the lowest giving activity lists for task owners who are responsible for activities in a particular cost centre or function.

The plan will always have a timetable for the work to be done. This may only be in bar chart form but should preferably be a network, which has been analysed to obtain the start and finish data for all the activities. As the project proceeds the planning documents will also contain progress information showing the current state of the project against the plan. In a long duration project the amount of detail included in the plan should vary with time. In the short term, which may be three to six months or in some cases more, there should be the full expansion of detail with progressively less from there on. The short-term horizon is, of course, moved forward at each update or at pre-planned times so that detail increases as the project moves forward.

The plan will include the budget for the project and financial statements showing expenditure, income and net cash flows adjusted to net present values. This part of the project plan may be restricted to certain levels of management, as may other parts if they contain confidential information.

Contained within the project plan there will also be plans for change and configuration management, for quality and for procurement together with a risk assessment showing both financial and technical risks and their possible impact on the project. These may be the work of separate groups within the parent organisation which specialise in the appropriate techniques, but for the project they report to the project manager who has to agree and approve their plans. If separate groups exist they will probably second a member to the project team to support the appropriate activities. If the project is large or is taking place physically distant from the originating organisation, there will probably be support teams, as part of the project team, for some or all of these aspects of the project plan.

## THE WORK BREAKDOWN STRUCTURE

Concurrently with the time-based plan a *work breakdown structure* (WBS) should also be produced, which will provide all those involved in the project with a hierarchically structured division of the work required in the project. The WBS can be structured in a number of alternative ways depending on the use to which it is to be put. Common ways are by division of the product into major components which are then split into subassemblies and so on down to components, by a functional breakdown or by cost centre code. The way chosen is usually related to the type of project and the industrial or public sector in which it is taking place.

In all cases, the lowest level in the WBS comprises groups of activities – or single activities if they are large enough – which are the responsibility of a named individual – the task owner. The task owner is responsible for identifying, estimating, planning, executing and reporting progress on the work in accordance with the project plan. The task owner is also responsible for the quality of the inputs to the project plan and for ensuring the progress data is accurately obtained and provided on time as required in the plan.

For each task a 'statement of work' (SOW) is required which describes the activities in the task in sufficient detail to provide an unambiguous statement of the task owner's commitment to the project and thus enable the activity list data to be complete. The data required will include estimated durations together with the resources required, costs, measures of performance including how any stated quality requirements are to be assessed, any risks and uncertainties and details of reporting procedures.



When the identified task is a subproject in its own right so that the task owner becomes a supplier to the project, the statement of work may need to take the form of a legal contract. This will certainly be so if the task owner is external to the parent organisation.

The project manager must assess and discuss the statements of work supplied by the task owners before agreeing the assignment of the work. Implicit in the agreement is the ability of the task owner to fulfil the commitment, as defined in the statement, at the time specified in the project plan. The task owner is thus committed to provide the required resources at the right time without interfering with other work.

Concurrent with the WBS, the logical relationships between project activities should be planned through the use of bar charts (where the logical relationships are difficult to express) or, preferably, through network diagrams in which the inclusion of the logical relationships is a part of the technique, whichever of the two types of diagram – of activity-on-arrow (AoA) or activity-on-node (AoN) – is used. Both bar charts and project network techniques (PNT) are presented in detail in later chapters and discussed further below.

There are differences of opinion among practitioners as to which comes first, the WBS or the network or an activity list. Your authors do not feel strongly about it and would suggest that whichever is most convenient for the project is what comes first. Whatever happens, the result is the same – the project plan and all that goes with it.

## INTRODUCTION TO PROJECT PLANNING TECHNIQUES

### The bar chart

When attempting to determine the completion date for any project, whether it be the building of a bridge, the mounting of a sales conference, the re-layout of a shop, the designing of a new piece of equipment or any other project, it is necessary to timetable all the activities that make up the task, that is to say a *plan* must be prepared. The need for planning has always been present, but the complexity and competitiveness of modern undertakings now requires that this need should be met rather than just recognised. The first attempt at a formal planning system was the *Gantt chart*.

In the Gantt chart the time that an activity should take is represented by a horizontal line, the length of that line being proportional to the duration time of that activity. In order that several activities can be represented on the same chart, a framework or ruling is set up, giving time flowing from left to right, the activities being listed from top to bottom (*see* Fig. 1.1)

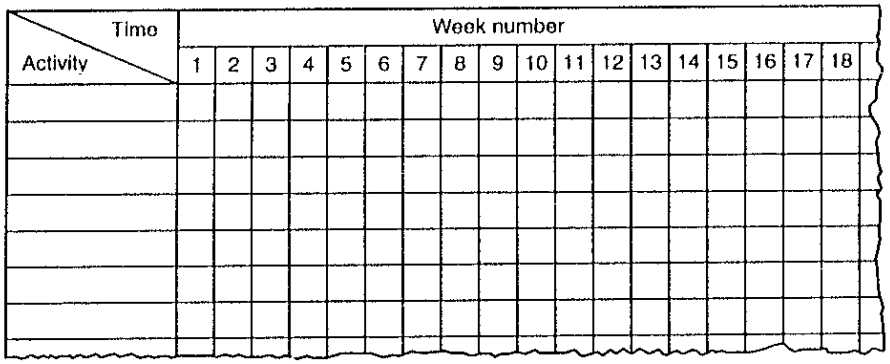



**Fig. 4.1 GANTT (Bar chart framework.)**

Assume, for the sake of simplicity, that there are three activities, A, B and C, which must be carried out in sequence and that the duration times are:

Activity A: 4 weeks
Activity B: 6 weeks
Activity C. 5 weeks

This is represented on the Gantt chart as shown in Fig. 4.2 and reveals quite clearly how work should progress. Thus, by the end of week 8, the whole of activity A and two-thirds of activity B should be complete.

To show how work is actually progressing, a bar or line can be drawn within the uprights of the activity symbol; the length of the bar representing the amount of the work completed. Thus, if 50 per cent of an activity is complete, a bar half the length of the activity symbol is drawn (*see* Fig. 4.3). This gives a very simple and striking representation of work done, particularly if a number of activities are represented on the same chart.

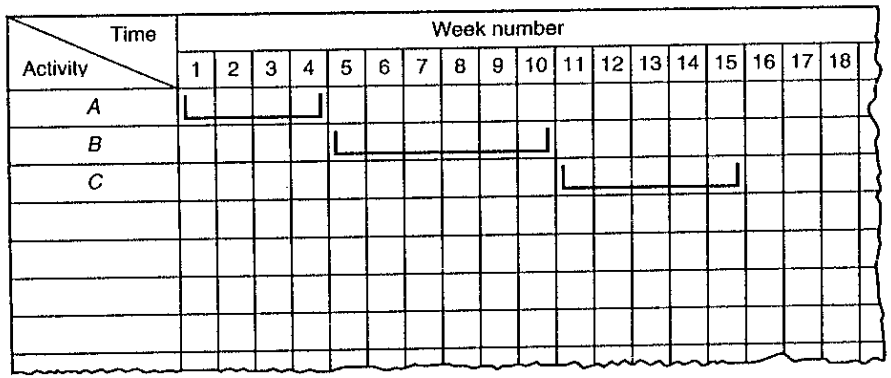



**Fig. 4.2 Three sequential activities.**

**Fig. 4.3 Representation of 50% of activity complete.**

If this chart has been correctly filled in and is viewed at the end of week 7, that is 'time now' (denoted by two small arrows at the top and bottom of the chart as shown in Fig. 4.4), then the following information is readily apparent:

*Activity A* should be complete and, in fact, is so.

*Activity B* should be 50 per cent complete, but, in fact, is only 17 per cent finished.

*Activity C* should not be started and, in fact, is not started.

*Activity D* should be 62 per cent complete and, in fact, is only 50 per cent finished.

*Activity E* should be 17 per cent complete and, in fact, is 50 per cent finished.

*Activity F* should be complete and, in fact, is not started.

*Activity G* should be 87 per cent complete and, in fact, is complete.

Thus we see that incomplete bars to the *left* of the cursor line mean under-fulfilment, while those to the *right* mean over-fulfilment. By the use

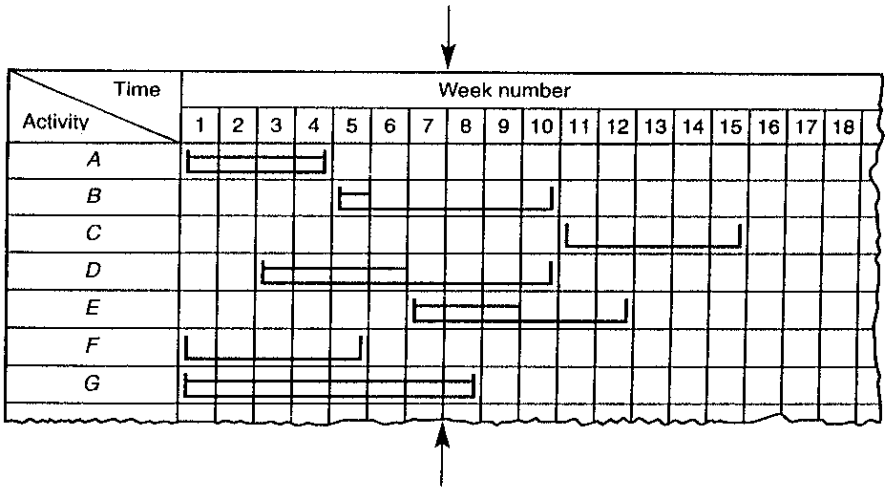



**Fig. 4.4 Representation of progress.**

of codes and/or symbols the reasons for any delays can be displayed and the whole chart can be very succinctly informative, combining both planning and the recording of progress. For many tasks the Gantt chart is unsurpassed, and its use has been very highly developed.

Though valuable, the Gantt chart presents three major difficulties; one concerning the problem of interrelationships, the second that of needing to take several decisions simultaneously and the third the problem of modifying the chart.

### *The problem of interrelationships*

Consider activity F in Fig. 4.4. It is shown here to start at the beginning of the project. However, it may be that there is another requirement, namely that it must be complete *before* activity C can start. This means that activity F can in fact 'slide' five weeks without detriment to the whole project. There may also be another activity, K (not shown in Fig. 4.4), which can start *only* when F is complete. How can these interrelationships be displayed? It is possible, in a small-scale work, to 'tie' bars by dotted lines but, if more than a few activities are concerned, the chart becomes so muddled as to be useless.

### *The problem of simultaneous decisions*

Locating an activity on a Gantt chart requires three simultaneous decisions to be made:

- *Method (logic)*: activity C is shown to follow activity B, that is, a decision on the way the project is to be carried out has to be made – the *logic* has to be decided.
- *Time:* any activity bar has a *length*, that is, a decision has been made on the time each activity will occupy.
- *Resources:* locating an activity in position implies that resources are available to carry out the activity at that time.

All projects have these three dimensions – logic, time, resources – and each is important. To require a planner to make decisions on these three features at one time is to set an impossible task, yet this is what is required when a Gantt chart is drawn. In practice, the decisions must be taken serially.

### *The problem of modifying the chart*

When changes to the plan are necessary – something which is inevitable even in the best planned project – the Gantt chart is virtually impossible to modify successfully both due to the physical problem of changing the chart and the lack of knowledge of the interrelationships which prevents the effect of a modification to one bar upon the other unmodified bars being reliably predicted.



The Gantt chart is now more generally referred to as a 'bar chart' – from which it was derived – and the latter term will be used in this text.

## Project network techniques

These difficulties were resolved by the development of the family of *project network techniques* and their charts or diagrams.

Project network techniques (PNTs) were developed in the mid-1950s and early 1960s when two types of network diagram originated. Essentially, these involve representing the proposed project as a diagram (or 'model') built up from a series of *arrows* and *nodes* (boxes or circles). The original structure of the model depends only upon the proposed method of carrying out the project and is drawn in such a way that the logical structure of the plan is easily observed and tested. It must be realised that as with any plan, the network model does not represent the 'best' or 'only' way of carrying out the project at any stage in its development. It represents the way the project has been planned on this occasion and forms a model for understanding and, when necessary, modifying the plan.

Once the diagram is believed to show an acceptable logic, times are set for the various constituents of the diagram (the duration times). A calculation is then carried out to discover the total duration of the project. If this is satisfactory, then no further action is necessary at this stage. If the total project time needs to be reduced then the activities dictating this time – the 'critical activities' – are examined to see whether they can be adequately shortened by using a different method or by changing the logic of the plan. It is foolish, indeed it should be impossible, to change an activity duration unless it is achieved by method or logic changes. Unfortunately, this is often unacceptable to senior executives who believe that issuing a fiat will solve a problem. 'I don't care what your plan says, the job has got to be done in less time with the resources you've got' is a cry which every planner must have heard many times. The exchange between method, logic and time continues until an acceptable situation is obtained.

Time and logic having been considered, it may be necessary – in some fortunate cases it is not – to consider the resources required by the plan as it now stands and the resources available. This can be done by moving through the network and adding up ('aggregating') the resources required in each time period. The aggregated resources ('loads') are compared with the resources available ('capacities') and, if requirement exceeds availability, the network is re-examined to see if any manipulation can take place to

'spread' the load satisfactorily. If not, then clearly either the available resources or the total project time (TPT) or both must be increased.

It should be realised that the 'time analysis' of the network sets all activities at their earliest time and that the resource aggregation forms an 'early start aggregation' so that any manipulation of the network to reduce the load must, inevitably, delay activities, but not necessarily the project completion date. The resulting interactions with other activities and their resource requirements can become extremely complex and, except for very small projects or simple situations, such manipulations should not be attempted without an appropriate computer program.

One of the very useful by-products of drawing a network is that the diagram forms a useful means of communication. It demonstrates how a project is to be completed, or it can enable an executive to pass on information to a successor or a subordinate. It is quite certain that the network will be seen and used by persons other than those who prepared it. With this 'communicating' aspect in mind, it is important from a practical point of view that activities should be *unequivocal* statements in *positive* terms that have *significance* within the context of the task being considered. Furthermore, wherever possible, constituents should be chosen in such a way that the responsibility for carrying out the activity can be explicitly assigned. When desired, networks can be easily transformed into bar charts, with the facility for incorporating change or being manipulated when required.

Broadly, there are two PNT families: the activity-on-arrow (AoA) family, where an activity is represented by an arrow; and the activity-on-node (AoN) family, where an activity is represented by a box or node. These two families each have their own advantages and their own adherents. The authors have used both extensively and believe that neither shows an overwhelming advantage over the other. It is necessary for some organisations to have both families available to meet the needs of their customers/clients. Care must be taken to avoid confusing the two families. There are currently many excellent computer programs available for both AoA and AoN. Both families have the characteristics of a good plan – namely, they are:

*Explicit* – often uncomfortably so: their clarity is uncompromising;

*Intelligible* – with education they are very intelligible – it is often easy to deduce the way in which the planner's mind was working;

*Capable of accepting change* – changes are easily made to a network: a working network that does not incorporate change is a rarity;

*Capable of being monitored* – The progress of the project as a whole and of the constituent parts can be very easily deduced *providing that the information on performance is fed back to the network with appropriate speed.*



PNT can be used in situations where the start and finish of the task can be identified: continuous or flow production is not susceptible to planning by PNT *although the setting up or pre-production work is*. The size of the project is of no consequence – networking has been used to plan a simple test procedure just as successfully as to plan the construction of a new town or the launch of a space ship.

As with any other new management tool, PNT will require to be introduced into an organisation with care. It is suggested that the following points should be observed:

- PNT is not a universal tool – there are many situations where it cannot be usefully employed. These situations are, in general, those where activity is continuous, for example, flow production. A PNT-type situation is characteristically one that has a definable start and finish.
- PNT is not a panacea – it does not cure all ills. Indeed, in itself it does not solve any problems, but it does expose situations in a way that will permit effective examinations both of the problems and the effects of possible solutions. However, the formulation and implementation of any solution will remain the responsibility of the appropriate manager.
- Networking must not be made a mystery, known only to a chosen few. All levels require to appreciate the method and its limitations and an extensive educational programme will be necessary to ensure that knowledge is spread as widely as possible.
- The person introducing networking into an organisation must be of sufficient stature and maturity to be able to influence both senior and junior personnel.
- Wherever possible, the early application of PNT should be to simple situations. If networking is first employed on a very difficult task it may fail, not because of the difficulty of networking but because of the difficulty of the task itself. However, the failure is likely to be attributed to PNT and the technique will be discredited.
- The first application of networking will undoubtedly excite considerable interest and attract many resources, both physical and managerial. This may starve other non-PNT-planned tasks to their detriment and it may produce exceptionally good results on the 'PNT job' that cannot be reproduced on later jobs. While it is impossible to avoid this 'halation' effect completely, its existence needs to be recognised.
- PNT will involve committal to, and the acceptance of, responsibilities expressed in quantified terms. Many supervisors find this difficult to accept and will often try to escape by creating unreal problems. It is vital to make it quite clear that PNT is not a punitive device: it is a tool to assist, not a weapon to assault.
- The purpose for which the network is to be used must be known in advance. A 'feasibility' network is likely to be different to a working net-

work. A network designed to control at one level in the organisation will differ from that used to control at a different level.

- Excessive detail must be eschewed. The authors have found, both in their own work and in talking to hundreds of network planners, that *excessive detail in the network is the most common cause of failure to use the network, and thus of the failure of the project*. A *very* approximate guide, for the majority of projects, is that few activities should be of less duration than 1 per cent of the total project duration. In addition, any network with more than a few hundred activities – say 400 at most – *must* be broken down into subprojects as part of the hierarchical planning and control process.

It must be realised that the duration time of an activity is the time that should be *expended* in carrying out the activity. It is not *necessarily* the time between the preceding and succeeding activities; for example, the preceding activity may finish in week 10. The succeeding activity may start in week 20 but the duration time of the activity itself may be only 4 weeks, in which case, the activity is said to possess *float* (in this case 6 weeks). This matter will be discussed more thoroughly later.

As with all scheduling techniques, the times assigned to activities must be realistic, that is to say they must take into account all current local circumstances. Using the work study officers' *standard* times is quite inappropriate here, since the actual work may not be performed 'at standard'. 'Actual' or 'observed' times are much more appropriate although the conditions then and on the current occasion should be checked for comparability. Unfortunately, in many cases the actual times are not available. It is extremely useful for performance data on resources and tasks to be collected, since time and resource performance may interact in unpredictable ways. Once recorded, these will assist the estimator in considering *current* circumstances and will lead to better duration estimates. Whatever the situation, however, the principle is clear: the duration times need to be *realistic* rather than *desirable*, and they should be accepted by those held responsible for their achievement.

## THE NETWORK AS A BUDGET

A financial budget is defined as:

> **A financial and/or quantitative statement, prepared prior to a defined period of time, of the policy to be pursued during that period for the purpose of attaining a given objective.**



This is a definition also of a network – indeed of any comprehensive project plan – and it is often very helpful to consider the network as *a budget in terms of time*. The cost accountant has developed much skill in the assembly and use of financial budgets and it is prudent to consider this experience when drawing and using networks. The authors have found this parallel particularly valuable when considering the detail that should be incorporated into a network. A hierarchy of networks is just as appropriate as a hierarchy of budgets: it will enable problems to be identified without a mass of unnecessary detail and it can locate responsibility at an appropriate point in the structure of a company.

Again, the experience of the cost accountant is pertinent: costs should be agreed with, not imposed upon, the manager concerned. *The Cost Handbook* (Ronald Press, New York) contains the following (Section 20.20):

> **Primary responsibility for preparation of the budgets should rest with the supervisors of the various segments of the business. For example . . . the sales manager should participate actively in the development of the sales budget, since he will be the individual primarily responsible for the execution of the sales plan. This general procedure is equally applicable to every other segment of the business and should be vigorously pursued . . .**
>
> **In this connection Francis (*Controller*, Vol. 22) points out that: 'Budgets are frequently developed by one or two key individuals . . . sometimes management without the prior knowledge or approval of the operating executives in the (various) departments. This is the worst type of budget procedure and quickly defeats the objectives of forward planning.'**

These comments would hold exactly if 'project plan' were substituted for 'budget'.

It cannot be too heavily stressed that the assessment of durations, resources and costs is a vital aspect of planning. Deductions from the network plan can be no better than the information used in the calculations; consequently it is imperative that the managers responsible for carrying out activities *must* be involved in the assessment. If they are not consulted they may well ignore the plan as totally unrealistic, with disastrous results for the project.

The time and resource data are essential for scheduling and, between them, form the basis for the costing of activities which then forms the project budget. For many organisations, particularly those in manufacturing industries, for whom project resource control is difficult since resource availabilities for project work are virtually unknown in advance, the project budget is the principal means of control for the project.

## CARD NETWORKING/BAR CHARTING

In an organisation which has networking/bar charting for project planning well established, it is possible to significantly reduce the time required for the preparation of such plans. In this approach, the basis of which is described in 'Speeded methods of network planning', by J.A. Larkin (*The Production Engineer*, February, 1968), plain cards are issued to each functional group concerned in the current project. These cards are used, one per activity, to record the details of all the activities for which the functional group is responsible in the project. The necessity for the use of the technique to be previously well established becomes apparent at this stage when it is realised that each group must plan at the same level of detail and use the same time units for durations.

When each functional group has completed its consideration of the project activities a meeting is convened to which it is essential that senior functional staff attend, since decisions taken at the meeting will affect the whole implementation of the project plan. The meeting should be held in a planning room equipped with magnetic or soft wallboards to which the activity cards can be stuck or pinned. The chair of the meeting guides a discussion of the project and as activities are discussed the cards representing them are added to the wallboards and the dependency interactions drawn in.

In this way the logic of the project is very rapidly established and any unforeseen problems emerge and can be discussed at once. It is said that in an experienced group a large and complex project can be set up in one day rather than the six to eight weeks it normally takes. The greatest virtue of the approach, other than the time saving, is that the functions discuss the problems of interaction directly with each other, rather than through the third party of the planning engineer, and are usually more co-operative in solving them at the senior level. The high level plan which results can be converted to the formalism of either AoA or AoN or to a bar chart as is required, and lower level plans with more detail can be prepared with confidence.

# Reading

Maylor, H. (1996) *Project Management*, Pitman Publishing, pp 44-76.

## CHAPTER 3

# Project planning

'Even the longest journey begins with a single step '

*The purpose of this chapter is to outline the scope and applications of planning methods that address the fundamental question – what needs to happen and when? The planning methods are the basis of a formalised approach by which the project manager will show how the requirements set out in the project brief will be met. There are a number of specific graphical techniques which are greatly facilitated by the use of computers. It is important in the first instance for the project manager to understand what is being done behind the 'graphical user interface' before committing to the output. This understanding of the methods involved will facilitate the process of finding a suitable system (see Chapter 4). Much planning should take place away from the computer as there are equally important matters such as the manipulation of time constraints to be considered.*

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3.3 Managing the planning process
3.4 Communicating project plans – using graphical techniques
3.5 Dealing with increased complexity through network diagrams
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## 3.1 PROJECT PLANNING AS A VALUE-ADDING ACTIVITY

The plan is the first step in providing the means of satisfying the requirements of the project owner or sponsor. It is the beginning of the project manager's input to ensuring that wherever possible, potential problems are identified and solved in advance. The plan is an explicit statement of the intended timing of project activities and the basis for estimating the resource requirements. Problem and error prevention, rather than rectification, is one of the main drivers of the planning process.

With the plethora of modern tools available through the medium of the computer, it is easy to forget the objectives of the plan, which are discussed here. Some of the basic techniques for establishing the logic and timing of activities are presented.

To call project planning a 'process' implies that there is a well defined route for the planner to take. This is not always clear, and a generic model of planning is difficult to construct.

Planning as a process involves the consumption of resources – it has costs associated with it. The project manager has to decide on the balance between the costs incurred in the process and the benefits that will reaped from it, as illustrated by Fig. 3.1. Costs associated with the planning process include:

- planned labour and associated expenses (travel, subsistence, etc.);
- planner's tools – may include computer assistance;
- cost of preparing the written plan – typing, binding, etc.;

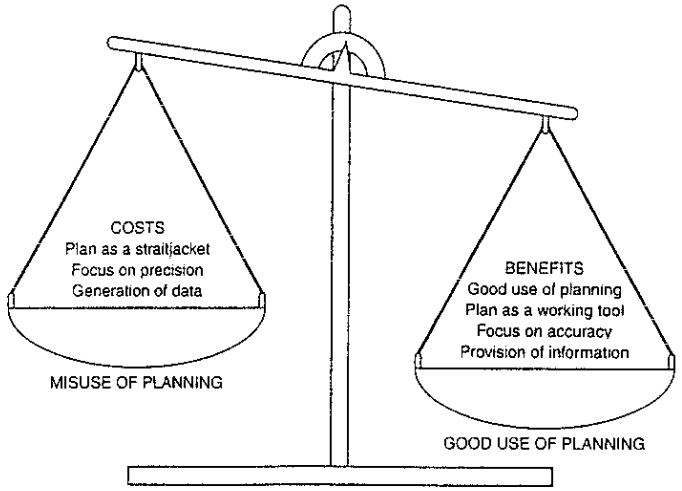


**Figure 3.1 Balancing costs and benefits**

- opportunity cost – what the planner and others drawn into the planning process could have been doing otherwise (e.g. working on an existing project).

In order for the planning process to be value-adding and not just cost-adding, the benefits of the activity have to be shown. These may be identified as:

- avoiding the costs of the chaos that would otherwise take place with an unplanned activity;
- providing a basis for a formalised evaluation process – filtering out projects that will provide a negative return;
- identifying problems in advance and being able to resolve them on paper.

The time that a planner spends preparing the plan should reflect the potential benefits of the activity. Figure 3.1 shows the positive and negative effects that the plan can have on project activities.

### The plan as a working tool or organisational straitjacket

One of the paradoxes that the project manager has to address is whether the output of the planning process remains a working tool or becomes a form of organisational 'straitjacket'. As a working tool plans are used to help decision-making and guide future activities. A well-balanced plan will guide the actions of the project team, without the need to define to the absolute detail level what each person will do for every minute of every day. As the Prudential Corporation move case illustrates (*see* Project management in practice), project plans should change as circumstances change. People can get so involved in the plan that the project objectives are forgotten with the planning becoming an end in itself, rather than a means to an end. If the techniques that follow are applied intelligently, changed circumstances can be matched by a new course of action. The phrase 'because it says so in the plan' is the defence of a person who, wrongly, does not use the plan as a working tool.

### Planning accuracy or precision?

A further argument which should be vocalised is the conflict between precision and accuracy – would you rather be roughly right or precisely wrong? The conflict is illustrated by 'The Sniper's Tale' below (Price, 1984):

> 'You are a sniper. You have a rifle with five rounds in the magazine. You spot your target; he is sitting under a tree leaning against its bole, his rifle resting across his knees. (He is a sniper as well, and he has got five rounds in his magazine.) You aim and fire five rapid shots. There are five thuds as each round bores into the tree trunk nine inches above your target's head. The holes they make are so tightly clustered you could cover them with a cigarette packet.
>
> That is precision.
>
> He jerks the muzzle of his gun and quickly fires his five bullets. The first hums past your ear, the second smacks into your thigh, the third clips your hair, the fourth smashes into your chest and the last drills into your head.
>
> That is accuracy.'



Often, what is termed a 'quick and dirty' approach (with the objective of being as accurate as possible) may be far more beneficial than months of painstaking planning (with the objective of being as precise as possible). Precision, as Frank Price describes it, is pretty; accuracy is deadly.

There is clearly a role for detail planning, but not before an overview plan has been worked through. Evaluating the overview reveals fundamental flaws in assumptions. Until this level of plan satisfies basic criteria such as financial or technical feasibility, detailed plans are inappropriate.

### Do plans provide information or just data?

One of the benefits of modern business systems is the ease and speed with which vast quantities of data can be generated. However, there is a tendency for managers to become overrun with data. Data is the numbers on the page. Information is the part or summary of that which can be usefully applied. The rest is just noise and clutters the thought and analysis process. One of the major roles of the project manager in projects, other than the smallest, will be to gather data from the relevant sources. Simply passing the data on is unlikely to be a value-adding activity. The project manager therefore needs to be not just a collector of data but a provider of information, usually in the form of management reports. The one page executive summary is one of the most beneficial of these in terms of information gleaned per time committed.

## 3.2 THE PROCESS OF PROJECT PLANNING – INPUTS, OUTPUTS AND THE PROCESS ITSELF

The process of project planning takes place at two levels. At one level, it has to be decided 'what' happens. This, the tactical level plan, then needs to be converted into a statement of 'how' it is going to be carried out (or operationalised) at the operational level. Figure 3.2 shows an activity model, as would be used to analyse systems of activity by considering the inputs, controls, outputs and mechanisms (ICOMs) for the activity (as discussed in Chapter 2). The inputs are the basis for what is going to be converted by the activity – in this case the project brief. The output is the project plan, or more specifically the project proposal. The controls provide the actuation, the constraints and the quality standards for the planning process in addition to its outputs and the mechanisms provide the means by which the process can happen.

At the operational level the way in which the proposal is generated should not be viewed as a one-off activity but should go through many cycles of suggestion and review before the 'final' document is produced. As Fig. 3.3 shows the first cycles are to provide the major revisions, where significant changes are made. Once these have been done and the project team are happy with the basic format, the last stages are those of refinement, where small adjustments are made.

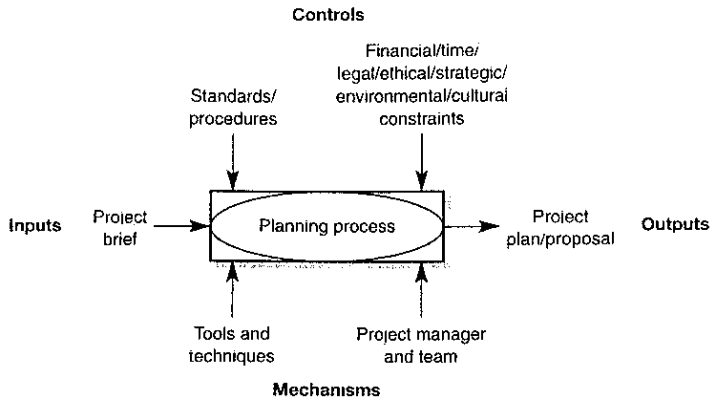


**Figure 3.2 Activity model using ICOMs**

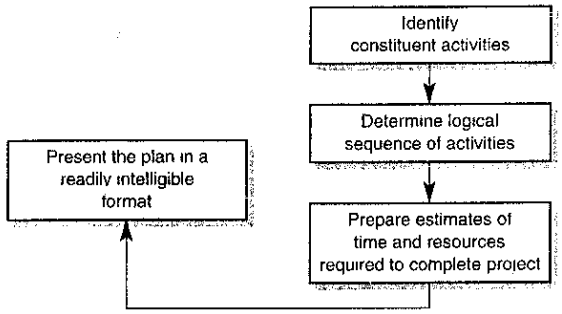


**Figure 3.3 The project planning process**

It is important for the overview to be verified first, before further effort is committed to planning at a detailed level – as discussed above. The life-cycle of planning shown in Fig. 3.3 shows the stages that the plan should go through. Cases such as the one given below are examples where the detail was considered before the major issues. As the example shows below, this is very wasteful of management time.

the
vn
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Business-plan meetings were serious affairs – they always were. The concept was quite attractive – to set-up an exclusive nursery school with an appealing teaching method in a smart area of the city. So far so good. This was, however, where the rough planning stopped and the group succumbed to the virus that plagues so many projects at this point – detailitus. The discussions were then



waylaid by the need to have safety-tyres on the school minibus and on the detailed wording of the liability insurance. No matter that the lag between the money being spent on the buildings and equipment and any income from fees received would create interest payments that the company could never hope to meet ...

The revision/refinement process considers the necessary sub-projects (if any), the results of any numerical analysis (may be financial, resource, risk analysis or some form of mathematical simulation), the element of 'gut feel' (also referred to as the subconscious or back-of-the-mind element) as well as experience. The sponsor and other stakeholders will usually have some input to be considered in this process.

## 3.3 MANAGING THE PLANNING PROCESS

Most projects of low complexity will bias the ratio of planning : action heavily towards the action. As complexity increases, so does the necessity for a formalised plan. This is both a systematic analysis of the project (which provides its own set of benefits) and an opportunity to show that the project manager has been systematic in the planning process (by showing the level of consideration that the project manager has given to issues). 'Traceability' has become a major issue in many companies – allowing products to be traced back to records of their constituent parts. The same is required of a project plan. In the event of an unsatisfactory result, for whatever reason, a good plan can show that the planner took every possible precaution to ensure that the result was positive. Conversely, should the project go particularly well, you will have an assignable cause for this – namely your planning!

The benefits of using a systematic methodology in planning include:

- breaking down complex activites into manageable chunks (*see* work breakdown structure);
- determining logical sequences of activities;
- providing an input to subsequent project management processes, including estimating the time and resources required for the project;
- providing a logical basis for making decisions;
- showing effects on other systems;
- filtering frivolous ideas and activities;
- providing a framework for the assessment of programmes (the post-project review process relies on comparing the achieved result with the original plan, particularly for the purpose of improving the planning process);
- being essential for the revision/refinement process;
- allowing lessons to be learned from practice;
- facilitating communication of ideas in a logical form to others.

The process of revision and refinement can only take place if there is something to review or refine. The plan in this case provides a basis for making an objective judgement on the project, i.e. the plan should speak for itself. Drucker (1955) described a category of products for which there was unlikely ever to be a financial case for developing as 'investments in managerial ego'. This categorisation can be applied to projects – those which are not going to provide any direct benefit to the organisation but will get approved because of the personality involved. Forcing a systematic project plan to be produced can eliminate some of the more frivolous projects.

The above benefits of being systematic are clearly desirable, though the route to achieving them requires that a planning sequence is followed. This is illustrated by Fig. 3.4. The first step is the identification of the constituent activities of the project. These should initially be broken down in a logical form (as was required of the Channel Tunnel case in the previous chapter), selecting the main areas for further deconstruction. Guides to the relative size of the individual chunks vary, but are in the range of two to ten per cent of the total project time. Where a chunk makes up less than two per cent of the total project, it should be combined with other activities. Any activity which makes up more than ten per cent of the project should be broken down one further level, if possible.

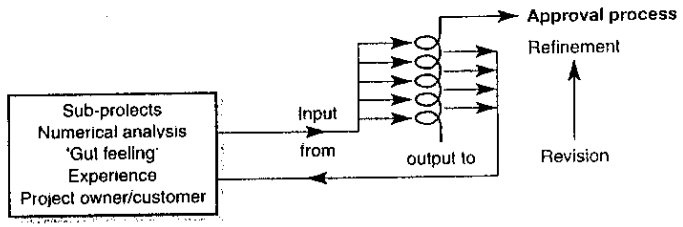



**Figure 3.4 Planning sequence**

It is human nature to tackle the easiest tasks first – sometimes only to find that an important step has been omitted. Any DIYer will happily recount stories of almost finishing a job, only to have to take it to pieces again because one of the first parts was missed out. The second stage is to determine the logical sequence of activities (e.g. close windows and remove aerial before driving car in to start car wash).

The third stage in the process involves the preparation of estimates for the time and resources required by the project. For small projects this may not be difficult, but where there are multiple projects with sub-projects, this can be a protracted and tortuous process. The techniques used for estimating are included in Chapter 4.



The fourth stage is the presentation of the plan. There are many techniques that can be used for presentation, some of which also facilitate analysis of the plans. The most popular ones are discussed in the following section.

It was stated at the start that the purpose of the project plan was to provide direction for the project. This is also the basis for assessing how the project is progressing. In the same way that a product or service may be judged in terms of its conformance to specification, a project is assessed as proceeding according to plan. The role that the plan plays in control is discussed in Chapter 6.

## 3.4 COMMUNICATING PROJECT PLANS – USING GRAPHICAL TECHNIQUES

Despite the diversity of projects being considered, one area of commonality between project managers is the use of various graphical techniques to:

- allow the construction of a comprehensive but comprehensible picture of the project activities;
- to communicate this with others.

The preference for graphical techniques is more than 'a picture telling a thousand words'. The whole revision/refinement process is built around people being able to understand what is going on. This is known as visibility, and is an essential feature of both the plan and the process.

The purpose of the graphical techniques is to illustrate the relationships between the activities and time. The simplest form is a horizontal bar chart, as in Fig. 3.5. This shows activity A represented by the shaded bar starting at time 1 and finishing at time 3. Multiple activities can be built up on the same chart, using the same timescale.

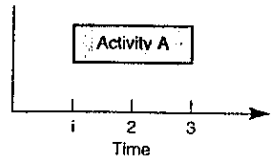



**Figure 3.5 Horizontal bar chart: activity A starts at time 1 and finishes at time 3**

A booking system for resources may use a similar format, as in Fig. 3.6. The shaded bars represent the amount of time that the resource is booked out for. It provides a readily interpreted record of who has booked the system and at which times.

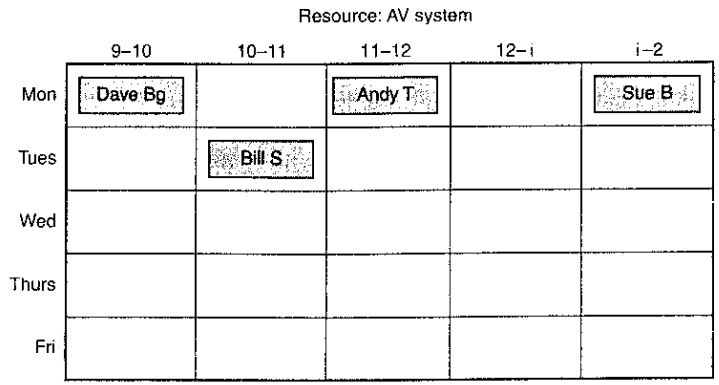



**Figure 3.6 Booking system**

The following example involves a dissertation planning exercise. The student has a number of options as to how to present the information. The supervisor, being a busy person, has asked for the information to be presented in graphical form.

## Planning a dissertation

The basic planning steps need to be followed here, namely:

- identify the constituent activities;
- determine their sequence;
- estimate the time and resources required;
- present the plan.

The time constraints are the start and end dates. The original statement looked as follows:

| Activity | Time |
|---|---|
| Project start date | 2/5 |
| 1 carry out literature review | 2/5–20/6 |
| 2 arrange visits | 20/6–4/7 |
| 3 prepare questionnaire | 4/7–25/7 |
| 4 review questionnaire | 25/7–8/8 |
| 5 deliver questionnaire | 8/8–26/9 |
| 6 analyse results | 26/9–2/11 |
| 7 write up | 2/11–9/12 |
| Hand-in date | 9/12 |

The requirement to present the plan graphically is the next step. In this case, simply showing a week by a star is possible and requires nothing more than pen and paper or typewriter/wordprocessor, as shown in Fig 3.7. In this example, there was



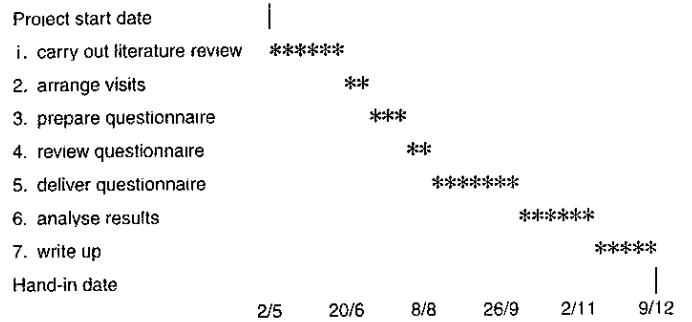



**Figure 3.7 Project plan in graphical form**

- a level of logic established and
- conventions used (time goes from left to right, activities are arranged top to bottom in order of their occurrence).

In addition the student has had to undertake two critical activities:

- forward schedule – started the activities at a given date and followed them forwards in time to determine the end date;
- backward schedule – looked at the time by which the project needed to be completed and worked the logic of activities backwards.

The tasks have had rough times allocated to see whether they meet the two constraints of start- and end-times. Where there was insufficient time, activities have been shortened. Any excess time (or slack) is used to lengthen activities.

Figure 3.8 shows an alternative presentation to the above. Logical links are indicated by the use of arrows. The head of the arrow points to an activity that cannot proceed until the activity at the tail of the arrow is completed. The diamond shapes on the chart are used to indicate 'milestones', i.e. important points in the life of the project – in this case the start and the hand-in dates.

Such a chart is often referred to as a Gantt or linked-bar chart as it is part of a family of techniques developed at the turn of the century by Henry Gantt. They were originally used in industrial planning.

Gantt charts, drawn by hand, are best suited to relatively simple projects, i.e.

- the number of activities and resources is low;
- the environment is fairly static;
- the time periods are relatively long – days and weeks rather than hours.

They do not make the link between time and cost and therefore do not provide a method for determining how resources should be optimally allocated, e.g. there are two activities, X and Y for which the times have been estimated and which use the same resource. If the resource could be shifted from activity X to activity Y, Y could be completed in a shorter time. X would obviously take longer, but how would this affect the project overall?

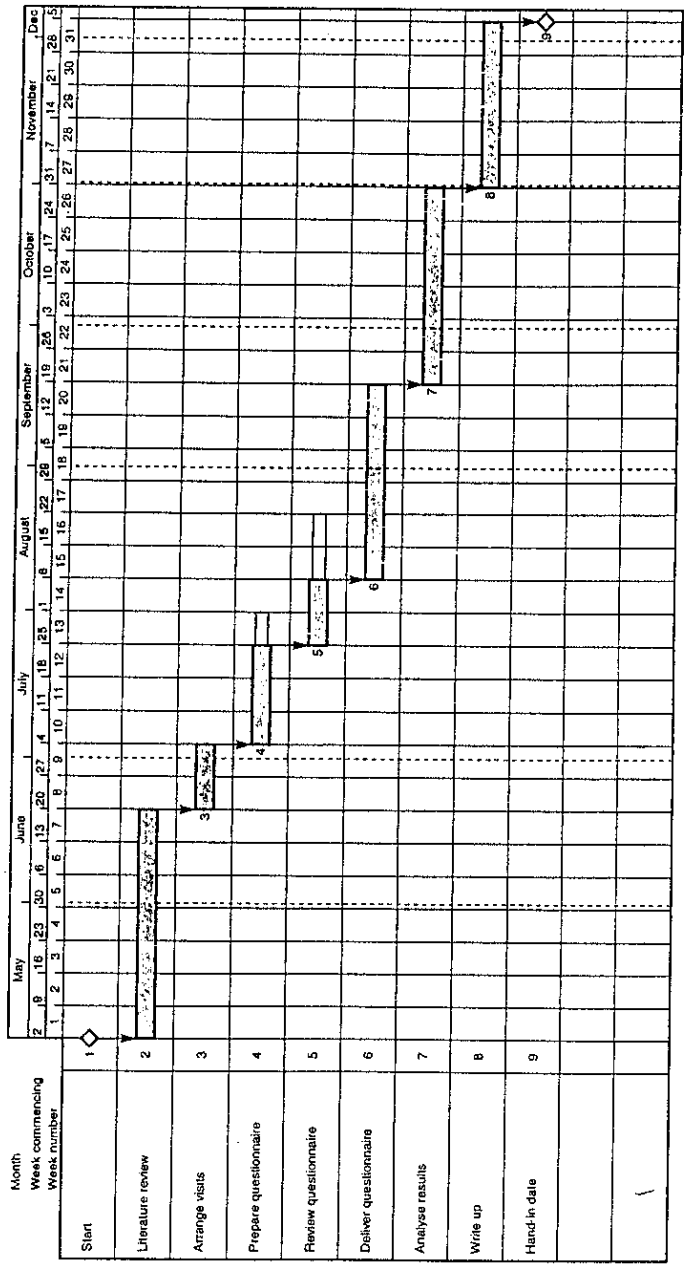



Figure 3.8 Logical links indicated by arrows



### Gantt charts – summary

| Good points | Limitations |
|---|---|
| • simple to draw and read | • difficult to update where there are many changes – charts can quickly become obsolete and therefore discredited |
| • good for static environments | • does not equate time with cost |
| • useful for providing overview of project activities | • does not help in optimising resource allocation (*see* Chapter 4) |
| • very widely used | |
| • the basis of the graphical interface for most PC software | |

## 3.5 DEALING WITH INCREASED COMPLEXITY THROUGH NETWORK DIAGRAMS

Gantt charts are very useful at low levels of complexity. Many projects, however, require a higher degree of sophistication and a method which better lends itself to analysis. Rather than representing an activity as a bar on a bar chart, it can be represented as either:

- an arrow – method known as activity-on-arrow (A-o-A);
- a node – method known as activity-on-node (A-o-N).

The former will be discussed in some detail to illustrate the basics of planning. The type of analysis that can be applied is then demonstrated before the use of A-o-N is covered. Finally there is a summary of the debate as to which method should be used.

## 3.6 CONSTRUCTING AND ANALYSING ACTIVITY-ON-ARROW (A-o-A) DIAGRAMS

Under this convention the following 'rules' apply:

- the arrow runs from left to right indicating time running from left to right;
- the arrow starts and ends at an event (for the present this can simply be defined as a 'point in time');
- the events and activities should be given unique identifiers or labels;

e.g. Activity A on its own would be represented as running from event 1 to event 2 as in Fig. 3.9.

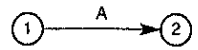



**Figure 3.9 Activity-on-arrow diagram**

The planning sequence identified above of:

- identify constituent activities;
- determine their sequence;
- estimate the times for each;

gives a verbal statement of the activities. This will now be converted into the A-o-A format for presentation, e.g. Fig. 3.10 shows two activities, A and B. B cannot start until A has finished and the times for A and B are five and seven days respectively. This logic is known as dependency and can be expanded as shown in Figs. 3.11 and 3.12. Here, more than one activity is dependent on another, in this case B, C and D cannot start until A has been completed. Likewise, H cannot start until all of E, F and G are finished.

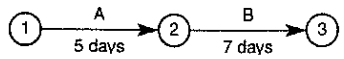



Figure 3.10

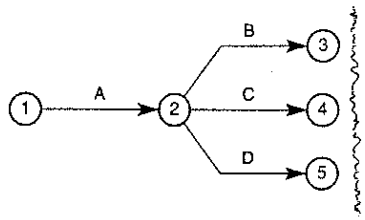



Figure 3.11

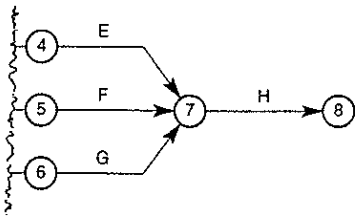



Figure 3.12

Essential to this convention, where all but the simplest projects are being described, is the addition of 'dummy' activities where:



- the logic of the activities' sequence needs to be preserved;
- the dummy will clarify the diagram;

e.g. taking the verbal statement that 'activity L is dependent on activity J but activity M is dependent on both activities J and K' would lead to Fig. 3.13. Simply writing it like this would add an extra logic dependency however – namely that of activity L on K. In this case a dummy is added to preserve the logic. It is written as a dotted arrow and in essence is an activity with zero duration, as in Fig. 3.14.

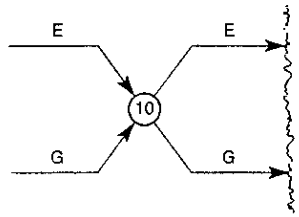



Figure 3.13

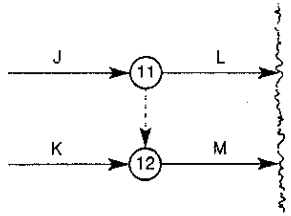



Figure 3.14

Clarification should be added where two activities have the same start and end events. Figure 3.15 should be expressed as Fig. 3.16.

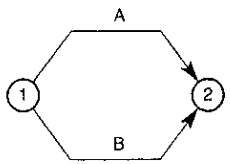



Figure 3.15

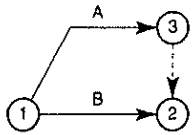



Figure 3.16

## 3.7 ANALYSING THE NETWORK – CRITICAL PATH ANALYSIS (CPA)

In order to provide a consistent format for the analytical phase, the convention for the symbols being used will be in accordance with BS6046:Part 2:1992, and are as Fig. 3.17. In order to facilitate the revision of diagrams, the event labels will now go up in tens or fives – allowing interim events to be added without modifying the labels to all subsequent events.

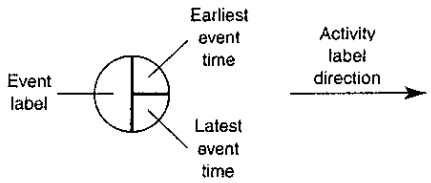



**Figure 3.17**

There are two new terms to be introduced to the diagrams:

- earliest event time (EET) – determined by the activities preceding the event and is the earliest time at which any subsequent activities can start;
- latest event time (LET) – is the same or later than the EET and is the latest time at which all the previous activities need to have been completed to prevent the whole network being held up.

Figure 3.18 shows the simplest case with a single activity.

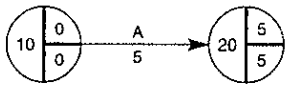



**Figure 3.18**

Figure 3.19 will be used as the basis for the calculation of the EET and LETs – please complete these on the page. The calculation of the two times is split into two processes.



### 1 Forward pass to determine the EET

The first event is assumed to start at time 0 for the purposes of this exercise. The forward pass starts at the first event (10) – the EET in this case is 0. Moving left to right, the subsequent activity time is added to this EET to give the EET for event 20,
i.e.:

EET at 20= [EET at 10] + [activity A duration]
= 0 + 5
= 5

This can now be added to the diagram. Event 20 should now look as in Fig. 3.19.

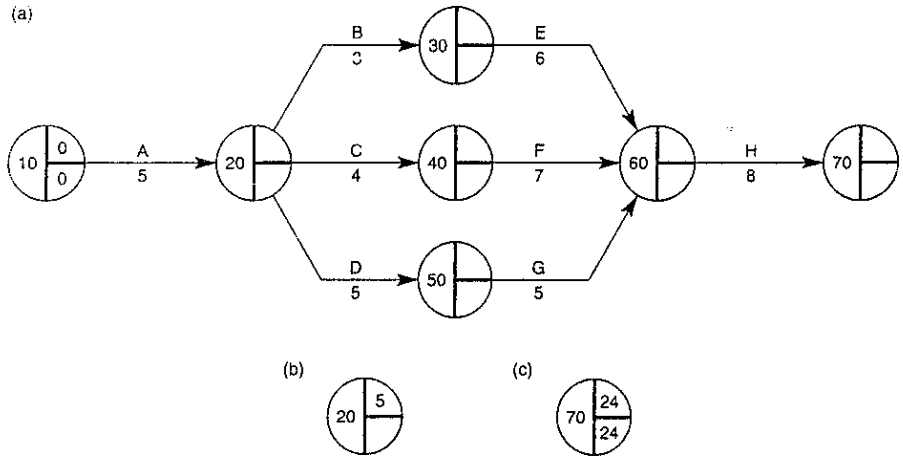



**Figure 3.19**

The same process can be repeated for events 30, 40 and 50. At event 30,

EET = [EET at 20] + [duration of connecting event (activity B)]
= 5 + 3
= 8

Add this to the diagram as before and do the EETs for 40 and 50.

The first logic snag occurs at event 60. As a reminder, the event cannot happen until all the preceding activities have been completed. In this case there are three possible EETs as shown:

[EET at 30] + [activity E duration] = 8 + 6 = 14
[EET at 40] + [activity F duration] = 9 + 7 = 16
[EET at 50] + [activity G duration] = 10 + 5 = 15

In this case the earliest that all the preceding activities will have been completed is 16 and therefore this is the EET at 60. Enter this on the diagram and calculate the EET for event 70.

The EET for the last event is the earliest time that the project can be completed, with the times and precedence given. Assuming that the project is required to be completed in the shortest possible time, this figure provides the basis for the next step.

## 2 Reverse pass to determine the LET

As the name suggests, the analysis begins on the right-hand side of the diagram at the last event. If the assumption that the project is required to be completed in the shortest possible time is correct, the LET of the final event is the same as its EET. Enter the LET for event 70 so that it looks like Fig. 3.19C.

Working backwards from the end, the next activity is 60, and the LET for 60 is calculated by:

LET at 60 = [LET at 70] – [activity H duration]
= 24 – 8
= 16

Do the same calculations for events 30, 40 and 50 and note that in two cases the EETs and LETs of those events are different. Enter these on the diagram. A logic challenge now occurs when trying to calculate the LET for event 20, similar to that in the forward pass. There are three possible LETs as shown:

[LET at 30] – [activity B duration] = 10 – 3 = 7
[LET at 40] – [activity C duration] = 9 – 4 = 5
[LET at 50] – [activity D duration] = 11 – 5 = 6

In making the choice we again check the logic definition of the LET as the time at which all previous activities (in this case, activity A) will have to be completed to prevent the whole network being held up. Here the LET is 5 – if it occurs any later than this, the whole project will be set back. Fill in the diagram and satisfy yourself that the original LET for event 10 still holds.

Having completed the network diagram, it is now possible to identify the critical path, which we define as:

**that sequence of activities which begin and end in events where the EET = LET**



You should now be able to identify this from the diagram. Marking the critical path activities should be done using one of the methods shown in Fig. 3.20.

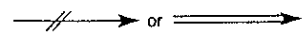



**Figure 3.20 Marks used for critical path activities**

We define *float* or *slack* as follows:

Float or slack = LET – EET

The critical path is that sequence of activities which have no float or slack. In the example, the path B–E has some slack which is evident at event 30. The slack is 10–8 = 2. Either of these events could:

- start late;
- take longer than expected;

or

- there could be a gap between E finishing and H starting;

and provided that the total of these deviations does not add up to more than two, the project will not be held up due to these activities.

The completed network is shown in Fig. 3.21.

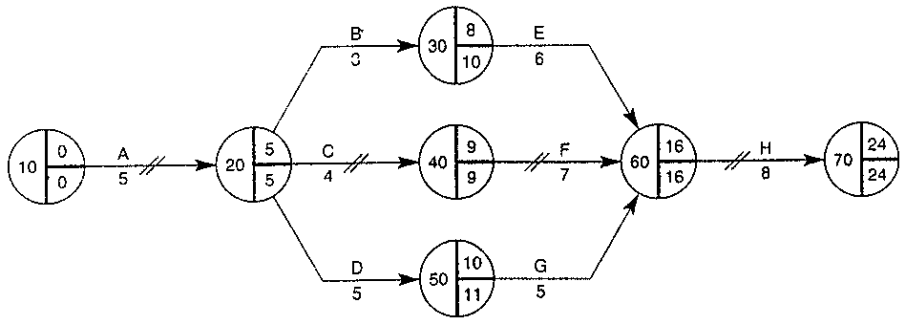



**Figure 3.21 Completed network**

## Origin of CPA

The 'invention' of the techniques that have been described here as CPA, are variously attributed depending on the particular book you read. The time of first use, 1957/8, is less debated. The first users/developers are credited as being:

- the Catalytic Construction Company for the planning and control of a construction project for Du Pont Corporation;
- Du Pont Consulting;
- I. Kelly of Remington-Rand and M. Walker of Du Pont.

Whoever instigated its usage, the applications are now far and wide – it is only a shame that unlike products such as the ring-pull on cans, such methods cannot be patented. If they were given just 0.1p every time a company had produced a CPA diagram....

## 3.8 ACTIVITY-ON-NODE (A-o-N) DIAGRAMMING

This technique is included here because some project managers and their customers prefer it as a convention of project planning. The relative advantages and disadvantages of each method are included later in the chapter.

The most common way of representing the activity-on-node is as Fig. 3.22.

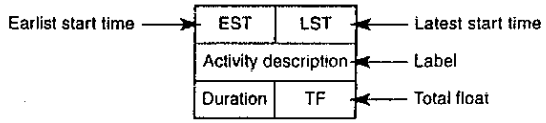



**Figure 3.22 Activity-on-node diagram**

Rather than talking about EETs and LETs, the method considers the activities directly and records the earliest start times and latest start times directly on the diagram as shown. The activities are linked in a similar way, but there are four ways in which activities can link (*see* Fig. 3.23). Precedence is indicated by arrows going from:

- the start of an activity (top left-hand or bottom left-hand corner of the box);
- the finish of an activity (middle of right-hand edge of box);

to:

- the start of an activity (middle of left-hand edge of box);
- the finish of an activity (top right-hand or bottom right-hand corner of the box).

The four ways in which activities can link are:

- finish-to-start – the second activity cannot start until the first has finished;
- start-to-start – the second activity cannot start until the first has started;
- finish-to-finish – the second activity cannot finish until the first has finished;
- start-to-finish – the second activity cannot finish until the first has started.



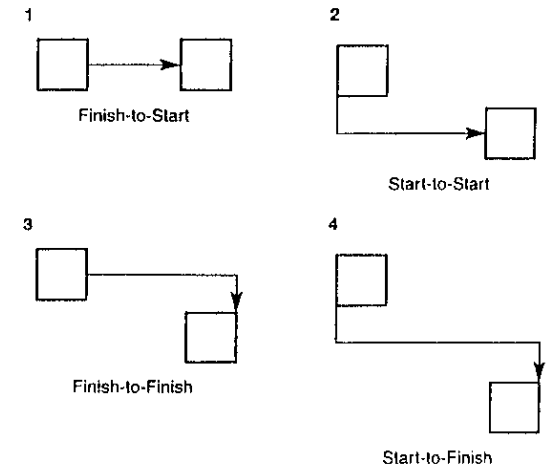



**Figure 3.23 Four ways to link A-o-N activities**

The arrows represent a potential time lag in the logic, e.g. if there was a figure, say 2 on the arrow in the start-to-finish case, the second activity could not finish until 2 time units after the first had started.

The way in which activities are built up into projects is very similar to that already discussed for A-o-A diagrams – with the exception that dummies are not required for clarification or maintaining logic flow.

## 3.9 ACTIVITY-ON-ARROW VERSUS ACTIVITY-ON-NODE METHOD

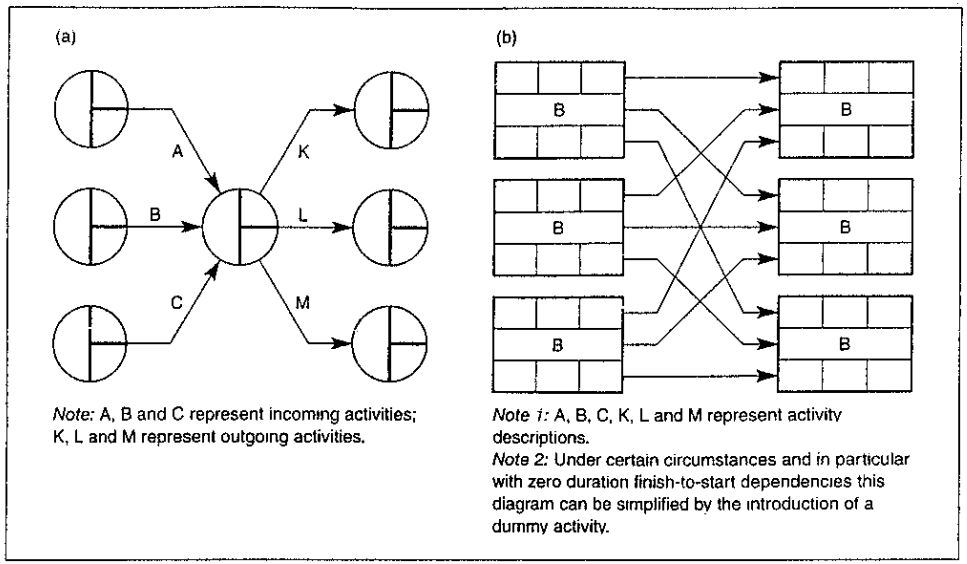
There is a preference for A-o-A diagrams amongst people who use such tools regularly. Whether this is because they were taught this technique first and have stayed with it or through conscious choice is debatable. There are many project managers who will not have A-o-A diagrams used in the planning of their projects. The debate can be roughly summarised as follows:

A-o-A

- easier to prepare and modify
- non-experts have a better change of understanding the network
- milestone events are easily marked
- where there are multiple predence relationships, (*see* Fig. 3.24) this is much more clearly illustrated

A-o-N

- easier to show complex relationships, e.g. start-to-finish precedence with time lag (complex with A-o-A)
- no dummy activities – keeps the number of activities the same as in the verbal statement (except when showing milestones)
- all the information about the activities is contained within the box – easier to ensure the right numbers are associated with the right activity




*Note:* A, B and C represent incoming activities; K, L and M represent outgoing activities.

*Note 1:* A, B, C, K, L and M represent activity descriptions.
*Note 2:* Under certain circumstances and in particular with zero duration finish-to-start dependencies this diagram can be simplified by the introduction of a dummy activity.

**Figure 3.24 Comparison of network drawing modes (a) activity-on-arrow (b) activity-on-node**

Example – planning the marketing of a new product

In Fig. 3.25 all the principles so far discussed are used to plan the launch of a new food product. It is possible through examining the EETs and LETs to determine which activities are on the critical path. The triangles are included to show milestones in the project, i.e. go-ahead, artwork go-ahead, production starts and sell-in starts. Trying to convey this volume of information through a verbal statement would clearly be a nightmare for both the planner and the reader, and would not lend itself to the kind of analysis that could be done with this diagram. Figure 3.25 was prepared using a computer program that would allow the information to be quickly displayed and altered as the situation changed.

## 3.10 DEALING WITH UNCERTAINTY – PROGRAMME EVALUATION AND REVIEW TECHNIQUE (PERT)

Programme evaluation and review technique (PERT) was developed for use in the Polaris project in the USA in 1958. Due to the success of the technique in this case, it was for a long time held up as the model that everyone should work to in planning projects. The technique is intended to deal with the likeli-



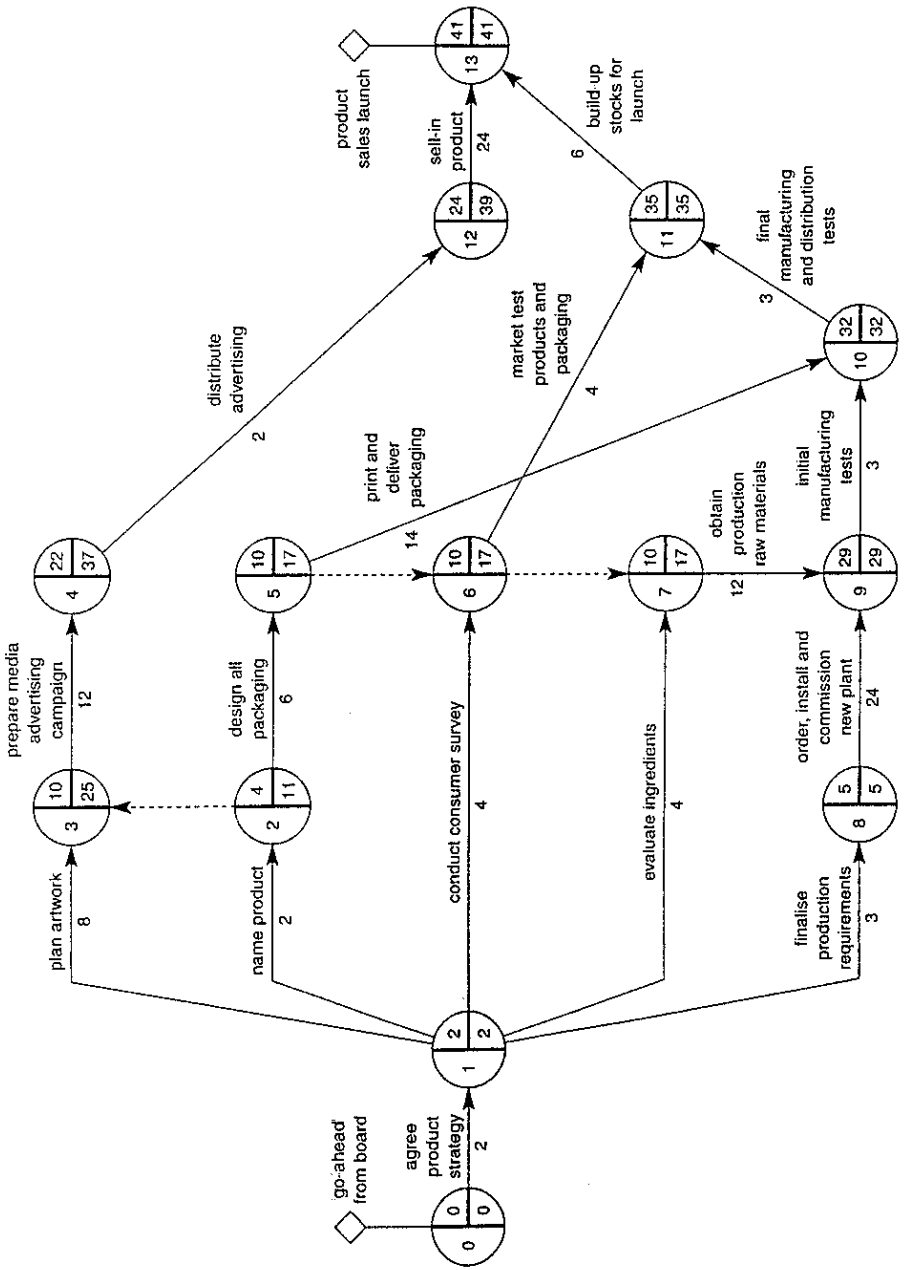



**Figure 3.25 Planning the launch of a new food product**

hood that the single value given as the estimated time for completion of activities, is going to have a degree of error associated with it. Instead of taking a single time, three time estimates for each activity are required:

- optimistic time – how long the activity would take if the conditions were ideal;
- most probable time – time if conditions were 'normal';
- pessimistic time – how long the activity would take if a significant proportion of the things that could go wrong, did go wrong.

There are an infinite number of possibilities as to how this range is distributed, e.g. optimistic and most probable times may be close together with the pessimistic time considerably different from the other two, or all three may be very close together. This flexibility in the distribution that is applied is one of the major appeals of the technique. The analysis that can be applied can be very simple or go into complex statistics that require the use of a computer. The following example can be done without the need for this. The project that was planned in the critical path analysis section (Section 3.7) was further examined, and the times estimated for each of the activities expanded to include an optimistic and a pessimistic element. The result is shown in Fig. 3.26.

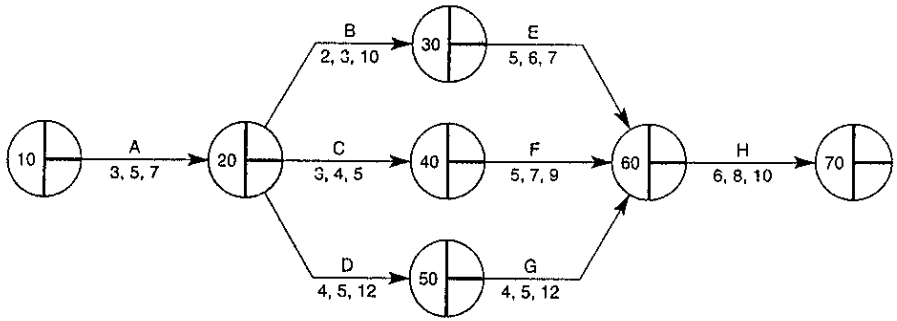



**Figure 3.26 Network diagram showing optimistic, most probable, and pessimistic times**

The activity arrows now have three figures associated with each in the order: optimistic, most likely, pessimistic, e.g. for activity A:

optimistic time = $o$ = 3
most likely time = $m$ = 5
pessimistic time = $p$ = 7

In order to schedule these activities, it is necessary to calculate the *expected* time for each activity. This is done by calculating:



expected time = $[o + 4m + p] / 6$

In the case of activity A, the expected time = [3 + [4 x 5] + 7] / 6 = 5.

For activity B, the expected time = [2 + [4 x 3] + 10] /6 = 4.

This distribution can be represented by Fig. 3.27.

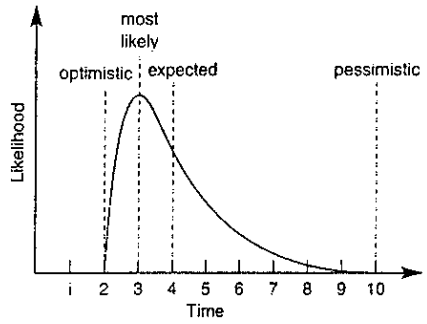



**Figure 3.27 Distribution of estimated times for an activity**

The example is now completed using the expected times shown in Table 3.1 instead of the most likely times and a critical path analysis carried out. Putting these figures into the network diagram and carrying out the forward pass gives a project expected duration of 25 days. This is not considerably different from the 24 days that the original analysis revealed. The reverse pass reveals that the critical path has changed. Originally it was ACFH, but with the consideration of the ranges of times, it is now ADGH.

**Table 3.1**

| *Activity* | *Optimistic time 0* | *Most likely time m* | *Pessimistic time p* | *Expected time* |
|---|---|---|---|---|
| A | 3 | 5 | 7 | 5 |
| B | 2 | 3 | 10 | 4 |
| C | 3 | 4 | 5 | 4 |
| D | 4 | 5 | 12 | 6 |
| E | 5 | 6 | 7 | 6 |
| F | 5 | 7 | 9 | 7 |
| G | 4 | 5 | 12 | 6 |
| H | 6 | 8 | 10 | 8 |

In order to save drawing the distribution each time, it is possible to compare activities in terms of a variance measure. This is calculated as follows:

variance of activity time = $[|p - o| / 6]^2$

## Explanation

The standard deviation of each activity's time is approximated to one sixth of the difference between the optimistic and pessimistic times. The variance = [standard deviation]$^2$. The standard deviation is the normal measure of spread in a set of numbers, and is represented by the Greek symbol σ or sigma. It is a characteristic of a normal distribution, that 99.7 per cent of the numbers being analysed (called the 'population') fall within +/– 3σ of the mean (the average of the population).

In this case, the extremes of the distribution are represented by the optimistic and pessimistic times. The normal distribution is applied and the approximation is made that between these two values, 99.7 per cent (practically all) of other values will lie. The upper limit (mean + 3σ) and the lower limit (mean – 3σ) are equated to the pessimistic and optimistic times respectively.

The distribution which is being considered is the beta distribution, a generic form of which the normal distribution is a special case. Unlike the normal distribution (represented by a bell-shaped curve) the beta distribution need not be symmetrical about the mean, i.e. it can be skewed. It therefore encompasses the effects of one of the values of *o* and *p* being further from *m* than the other.

Applying this to the example

variance for activity B = $[|10 - 2| / 6]^2 = 1.78$

for activity A = $[|7 - 3| / 6]^2 = 0.44$

Thus we have a mathematical measure for what can be seen from the figures, that the variance (as a measure of uncertainty with this activity) is much higher for activity B than for A, i.e. there is more uncertainty in the completion of B than A.

Figures, such as the variance, are of greatest practical use in estimating the likelihood that a set of activities will be completed within a certain time. The steps involved are:

1 Calculate the variance for each activity.
2 Calculate the variance for each path (a sequence of activities that will take you from the first event to the last – there are generally many paths through networks) in the network diagram. This is done by summing the variances of all the activities on the path.
3 Calculate the standard deviation for that path:
   $\sigma_{path}$ = square root of the variance.
4 Identify the time within which you wish to complete the activities.
5 Calculate the value for z determined by:
   $z = |\text{specified time} - \text{expected time}| / \sigma_{path}$.



**Table 3.2(a) Areas under the standardised normal curve from $-\infty$ to $-z$**

| .09 | .08 | .07 | .06 | .05 | .04 | .03 | .02 | .01 | .00 | z |
|---|---|---|---|---|---|---|---|---|---|---|
| .0002 | .0003 | .0003 | .0003 | .0003 | .0003 | .0003 | .0003 | .0003 | .0003 | –3.4 |
| .0003 | .0004 | .0004 | .0004 | .0004 | .0004 | .0004 | .0005 | .0005 | .0005 | –3.3 |
| .0005 | .0005 | .0005 | .0006 | .0006 | .0006 | .0006 | .0006 | .0007 | .0007 | –3.2 |
| .0007 | .0007 | .0008 | .0008 | .0008 | .0008 | .0009 | .0009 | .0009 | .0010 | –3.1 |
| .0010 | .0010 | .0011 | .0011 | .0011 | .0012 | .0012 | .0013 | .0013 | .0013 | –3.0 |
| .0014 | .0014 | .0015 | .0015 | .0016 | .0016 | .0017 | .0018 | .0018 | .0019 | –2.9 |
| .0019 | .0020 | .0021 | .0021 | .0022 | .0023 | .0023 | .0024 | .0025 | .0026 | –2.8 |
| .0026 | .0027 | .0028 | .0029 | .0030 | .0031 | .0032 | .0033 | .0034 | .0035 | –2.7 |
| .0036 | .0037 | .0038 | .0039 | .0040 | .0041 | .0043 | .0044 | .0045 | .0047 | –2.6 |
| .0048 | .0049 | .0051 | .0052 | .0054 | .0055 | .0057 | .0059 | .0060 | .0062 | –2.5 |
| .0064 | .0066 | .0068 | .0069 | .0071 | .0073 | .0075 | .0078 | .0080 | .0082 | –2.4 |
| .0084 | .0087 | .0089 | .0091 | .0094 | .0096 | .0099 | .0102 | .0104 | .0107 | –2.3 |
| .0110 | .0113 | .0116 | .0119 | .0122 | .0125 | .0129 | .0132 | .0136 | .0139 | –2.2 |
| .0143 | .0146 | .0150 | .0154 | .0158 | .0162 | .0166 | .0170 | .0174 | .0179 | –2.1 |
| .0183 | .0188 | .0192 | .0197 | .0202 | .0207 | .0212 | .0217 | .0222 | .0228 | –2.0 |
| .0233 | .0239 | .0244 | .0250 | .0256 | .0262 | .0268 | .0274 | .0281 | .0287 | –1.9 |
| .0294 | .0301 | .0307 | .0314 | .0322 | .0329 | .0336 | .0344 | .0351 | .0359 | –1.8 |
| .0367 | .0375 | .0384 | .0392 | .0401 | .0409 | .0418 | .0427 | .0436 | .0446 | –1.7 |
| .0455 | .0465 | .0475 | .0485 | .0495 | .0505 | .0516 | .0526 | .0537 | .0548 | –1.6 |
| .0559 | .0571 | .0582 | .0594 | .0606 | .0618 | .0630 | .0643 | .0655 | .0668 | –1.5 |
| .0681 | .0694 | .0708 | .0721 | .0735 | .0749 | .0764 | .0778 | .0793 | .0808 | –1.4 |
| .0823 | .0838 | .0853 | .0869 | .0885 | .0901 | .0918 | .0934 | .0951 | .0968 | –1.3 |
| .0985 | .1003 | .1020 | .1038 | .1056 | .1075 | .1093 | .1112 | .1131 | .1151 | –1.2 |
| .1170 | .1190 | .1210 | .1230 | .1251 | .1271 | .1292 | .1314 | .1335 | .1357 | –1.1 |
| .1379 | .1401 | .1423 | .1446 | .1469 | .1492 | .1515 | .1539 | .1562 | .1587 | –1.0 |
| .1611 | .1635 | .1660 | .1685 | .1711 | .1736 | .1762 | .1788 | .1814 | .1841 | –0.9 |
| .1867 | .1894 | .1922 | .1949 | .1977 | .2005 | .2033 | .2061 | .2090 | .2119 | –0.8 |
| .2148 | .2177 | .2206 | .2236 | .2266 | .2296 | .2327 | .2358 | .2389 | .2420 | –0.7 |
| .2451 | .2483 | .2514 | .2546 | .2578 | .2611 | .2643 | .2676 | .2709 | .2743 | –0.6 |
| .2776 | .2810 | .2843 | .2877 | .2912 | .2946 | .2981 | .3015 | .3050 | .3085 | –0.5 |
| .3121 | .3156 | .3192 | .3228 | .3264 | .3300 | .3336 | .3372 | .3409 | .3446 | –0.4 |
| .3483 | .3520 | .3557 | .3594 | .3632 | .3669 | .3707 | .3745 | .3783 | .3821 | –0.3 |
| .3859 | .3897 | .3936 | .3974 | .4013 | .4052 | .4090 | .4129 | .4168 | .4207 | –0.2 |
| .4247 | .4286 | .4325 | .4364 | .4404 | .4443 | .4483 | .4522 | .4562 | .4602 | –0.1 |
| .4641 | .4681 | .4721 | .4761 | .4801 | .4840 | .4880 | .4920 | .4960 | .5000 | –0.0 |

6 Refer to Table 3.2 – the value of z corresponds to a probability (expressed between 0 and 1). This is the probability that the activity path will be completed within the time identified in 4.
7 The probability that all the paths that have been considered will be finished in the given time, is found by multiplying the probabilities for each of the paths together.

**Table 3.2(b) Areas under the standardised normal curve from $-\infty$ to $+z$**

| z | .00 | .01 | .02 | .03 | .04 | .05 | .06 | .07 | .08 | .09 |
|---|---|---|---|---|---|---|---|---|---|---|
| .0 | .5000 | .5040 | .5080 | .5120 | .5160 | .5199 | .5239 | .5279 | .5319 | .5359 |
| .1 | .5398 | .5438 | .5478 | .5517 | .5557 | .5596 | .5636 | .5675 | .5714 | .5753 |
| .2 | .5793 | .5832 | .5871 | .5910 | .5948 | .5987 | .6026 | .6064 | .6103 | .6141 |
| .3 | .6179 | .6217 | .6255 | .6293 | .6331 | .6368 | .6406 | .6443 | .6480 | .6517 |
| .4 | .6554 | .6591 | .6628 | .6664 | .6700 | .6736 | .6772 | .6808 | .6844 | .6879 |
| .5 | .6915 | .6950 | .6985 | .7019 | .7054 | .7088 | .7123 | .7157 | .7190 | .7224 |
| .6 | .7257 | .7291 | .7324 | .7357 | .7389 | .7422 | .7454 | .7486 | .7517 | .7549 |
| .7 | .7580 | .7611 | .7642 | .7673 | .7703 | .7734 | .7764 | .7794 | .7823 | .7852 |
| .8 | .7881 | .7910 | .7939 | .7967 | .7995 | .8023 | .8051 | .8078 | .8106 | .8133 |
| .9 | .8159 | .8186 | .8212 | .8238 | .8264 | .8289 | .8315 | .8340 | .8365 | .8389 |
| 1.0 | .8413 | .8438 | .8461 | .8485 | .8508 | .8531 | .8554 | .8577 | .8599 | .8621 |
| 1.1 | .8643 | .8665 | .8686 | .8708 | .8729 | .8749 | .8770 | .8790 | .8810 | .8830 |
| 1.2 | .8849 | .8869 | .8888 | .8907 | .8925 | .8944 | .8962 | .8980 | .8997 | .9015 |
| 1.3 | .9032 | .9049 | .9066 | .9082 | .9099 | .9115 | .9131 | .9147 | .9162 | .9177 |
| 1.4 | .9192 | .9207 | .9222 | .9236 | .9251 | .9265 | .9279 | .9292 | .9306 | .9319 |
| 1.5 | .9332 | .9345 | .9357 | .9370 | .9382 | .9394 | .9406 | .9418 | .9429 | .9441 |
| 1.6 | .9452 | .9463 | .9474 | .9484 | .9495 | .9505 | .9515 | .9525 | .9535 | .9545 |
| 1.7 | .9554 | .9564 | .9573 | .9582 | .9591 | .9599 | .9608 | .9616 | .9625 | .9633 |
| 1.8 | .9641 | .9649 | .9656 | .9664 | .9671 | .9678 | .9686 | .9693 | .9699 | .9706 |
| 1.9 | .9713 | .9719 | .9726 | .9732 | .9738 | .9744 | .9750 | .9756 | .9761 | .9767 |
| 2.0 | .9772 | .9778 | .9783 | .9788 | .9793 | .9798 | .9803 | .9808 | .9812 | .9817 |
| 2.1 | .9821 | .9826 | .9830 | .9834 | .9838 | .9842 | .9846 | .9850 | .9854 | .9857 |
| 2.2 | .9861 | .9864 | .9868 | .9871 | .9875 | .9878 | .9881 | .9884 | .9887 | .9890 |
| 2.3 | .9893 | .9896 | .9898 | .9901 | .9904 | .9906 | .9909 | .9911 | .9913 | .9916 |
| 2.4 | .9918 | .9920 | .9922 | .9925 | .9927 | .9929 | .9931 | .9932 | .9934 | .9936 |
| 2.5 | .9938 | .9940 | .9941 | .9943 | .9945 | .9946 | .9948 | .9949 | .9951 | .9952 |
| 2.6 | .9953 | .9955 | .9956 | .9957 | .9959 | .9960 | .9961 | .9962 | .9963 | .9964 |
| 2.7 | .9965 | .9966 | .9967 | .9968 | .9969 | .9970 | .9971 | .9972 | .9973 | .9974 |
| 2.8 | .9974 | .9975 | .9976 | .9977 | .9977 | .9978 | .9979 | .9979 | .9980 | .9981 |
| 2.9 | .9981 | .9982 | .9982 | .9983 | .9984 | .9984 | .9985 | .9985 | .9986 | .9986 |
| 3.0 | .9987 | .9987 | .9987 | .9988 | .9988 | .9989 | .9989 | .9989 | .9990 | .9990 |
| 3.1 | .9990 | .9991 | .9991 | .9991 | .9991 | .9992 | .9992 | .9992 | .9993 | .9993 |
| 3.2 | .9993 | .9993 | .9994 | .9994 | .9994 | .9994 | .9994 | .9995 | .9995 | .9995 |
| 3.3 | .9995 | .9995 | .9995 | .9996 | .9996 | .9996 | .9996 | .9996 | .9996 | .9997 |
| 3.4 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9998 |

This method is best illustrated by an example. If the middle section of the previous example is used, and the events 20-60 considered, the steps are as follows:

1 Calculate the variance for each activity (shown in Table 3.3).
2 Now it is necessary to identify the paths. There are several rules regarding the selection of paths for this process:



**Table 3.3**

| Activity | Optimistic time o | Most likely time m | Pessimistic time p | Variance |
|---|---|---|---|---|
| B | 2 | 3 | 10 | 1.78 |
| C | 3 | 4 | 5 | 0.11 |
| D | 4 | 5 | 12 | 1.78 |
| E | 5 | 6 | 7 | 0.11 |
| F | 5 | 7 | 9 | 0.44 |
| G | 4 | 5 | 12 | 1.78 |

- each activity must be on only one path – where activities are shared between several paths, the one that is the critical path should be used;
- activities on different paths need to be independent – there should be no unwritten logic relationship between activities on different paths.

With these in mind the three paths that need to be considered here are:

B – E
C – F
D – G

The following steps are calculated in Table 3.4. The variances are then summed for each path.

**Table 3.4**

| Path | Path variance | Standard deviation | z | Probability of completion in 11 days |
|---|---|---|---|---|
| B – E | 1.78+0.11 = 1.89 | 1.37 | [11–10]/1.37 = 0.73 | 0.7673 |
| C – F | 0.11+0.44 = 0.55 | 0.74 | [11–11]/0.74 = 0.0 | 0.5000 |
| D – G | 1.78+1.78 = 3.56 | 1.87 | [11–12]/1.87 = –0.53 | 0.2981 |

3 The standard deviations are then calculated.
4 The time required for completion is arbitrarily 11 days.
5 The z values are added.
6 The probabilities are derived from Table 3.2 (pp. 69–70).
7 The probability of each of these times being achieved is clearly highest where the expected time was less than the time required for completion (path B–E). These values are now required to find the probability that all three paths will be completed in 11 days. This is achieved through the multiplication of the three probabilities. In this case, the probability that the three paths will all be completed in 11 days is:

$$0.7673 \times 0.5000 \times 0.2981 = 0.1143$$

i.e. there is less than a 12 per cent chance that this part of the project will be completed in 11 days.

Many authors choose to use PERT as the generic title for network techniques. This is perfectly valid – the original CPA that was carried out using a single value for the estimated time can be taken as a special case of PERT, where the most likely = optimistic = pessimistic time.

### The use of PERT in practice

As mentioned at the start, PERT was very popular in the 1960s. It appears to be less well used today as many project managers feel that the additional complexity is not justified by the return in the accuracy of the plans produced. Also, it was suggested that in organisations where this kind of planning is prevalent, the use of PERT can encourage people to be less accurate in their forecasting.

## 3.11 PLANNING WITH STANDARDS – FOUR FIELDS MAPPING

A related graphical technique, used in Japan and finding favour elsewhere, is that of four fields mapping. As shown in Fig. 3.28, it is a way of relating four information fields:

- the team members;
- the logical phases of an activity;
- tasks to be performed including decisions made;
- the standards that apply for each task.

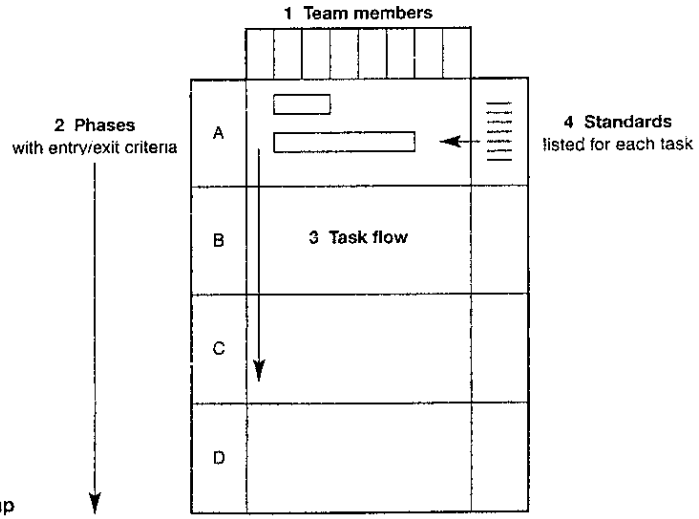



**Figure 3.28 Four fields map**
(*Source:* Dimancescu, 1992)



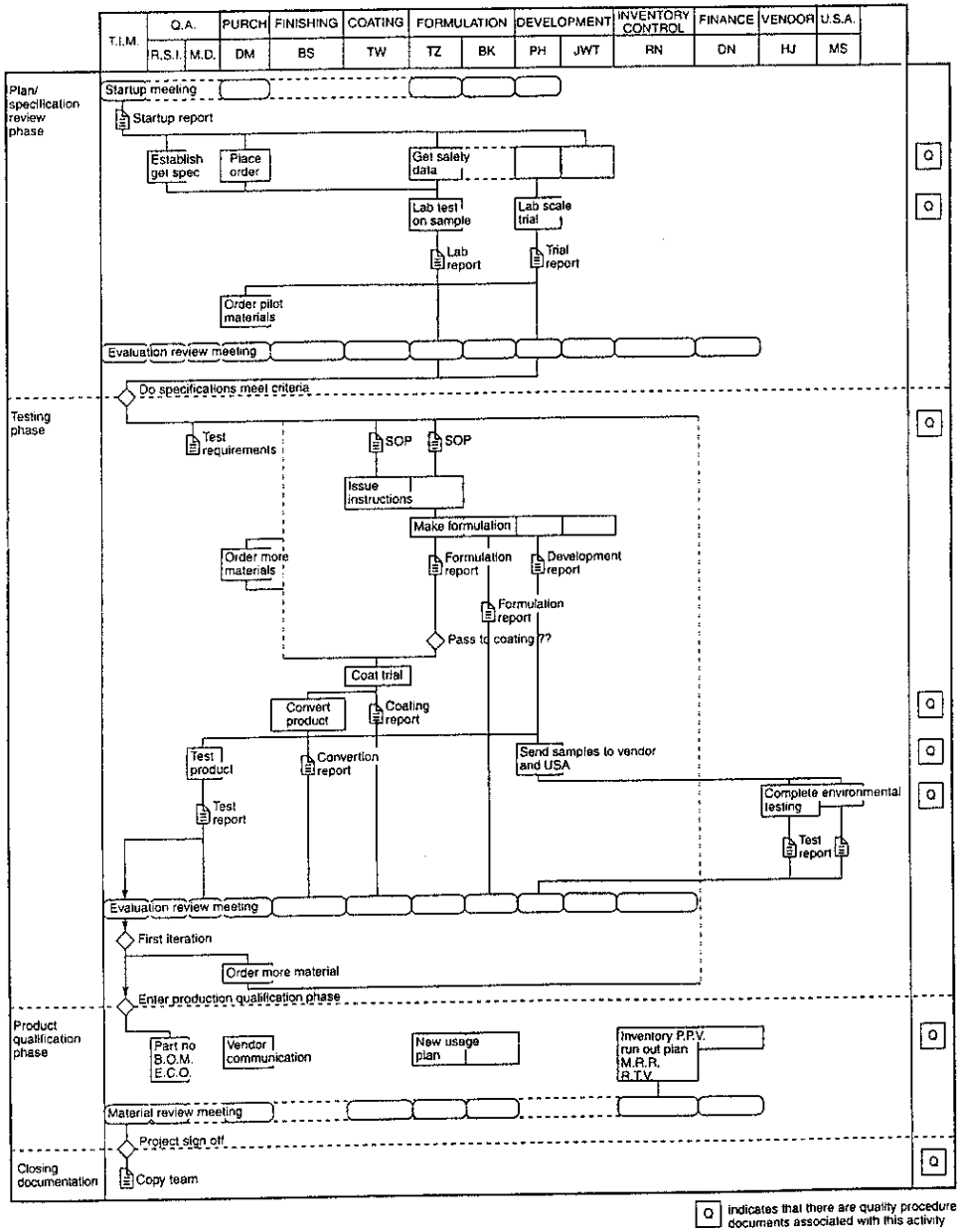



**Figure 3.29 The use of four fields mapping in planning the introduction of a new coating material**

By incorporating the standards element into the plan, not only is the time and activity planned in detail, but the controls also specified so that the sharing of information across an organisation needed to make the project work can take place.

Figure 3.29 shows the use of the technique in the selection of a replacement coating product used in the manufacture of computer disks. The entry and exit criteria at each phase ensure that the project does not move on without the team having met certain criteria at that point. For example, at the end of the first phase, the outcome must be that the specifications meet the criteria set. No phase can be completed until all errors have been corrected and the causes identified. This, as can be seen, does not sit terribly comfortably with the conventional ideas of project planning where activites just proceed at some stated point in time, regardless.

PROJECT MANAGEMENT IN PRACTICE: **ADOPTING A STANDARD FOR PROJECT PLANNING – USEFUL DISCIPLINE OR UNNECESSARY CONSTRAINT?**

Should all the project plans produced in an organisation conform to a particular set of rules as to how they should be constructed such as:

- the notation used in diagrams;
- the use of time-scaled axes (the left-to-right scale where distance on the diagram is proportional to time);
- the units to be used;
- who can construct the diagrams;
- what procedure, if any, should be used for checking the plans prior to their issue;
- the filing, storage and control of plans to ensure that only the current version is being worked to;
- the format of reports;

... or is this just creating unnecessary bureaucracy?

The role of such working practices in organisations will be covered in Chapter 6. There was a clear divide amongst the project managers who were questioned on this issue, which can be summarised in the following composite cases.

**Example 1 – Makesure Electronics**

There are very tight controls as to how project plans may be drawn up. The bureaucracy of the company is considered necessary to ensure that the end-customers of the projects are kept happy (generally military procurement agencies). The correct paperwork is essential to the project and would be returned to the originator if all the boxes on the accompanying forms are not fully completed. It is generally felt that the process prevents any dynamic activity taking place, but that is appropriate for the market they are in.

**Example 2 – internal consultancy in a public service industry**

The role of the consultancy is one of a team that moves in to help a department solve a particular problem before moving on to the next. The team is required to



be dynamic and respond quickly to changes. Plans are mainly for the use of the team in structuring how they tackle the problem. No particular convention is adhered to and there are no rules which the team believe would constrain the problem-solving process. This often causes problems with their 'customers' many of whom believe in the benefits of the more formalised approach but who nonetheless are generally satisfied with the results of their work.

The arguments for and against using a highly formalised approach may be summarised as follows:

| *For formalisation* | *Against formalisation* |
|---|---|
| • ensures that everyone is working to the same standard – gives the best chance that the plans are universally understood | • restricts creative activity |
| • imposes a degree of discipline into the process | • standardisation is to some extent taken care of by the use of a common project planning software package |
| • can be used as a marketing feature for the project organisation | • can mask problems of disorder |
| • is a requirement for some markets, e.g. some construction tenders, government contracts | • costly to implement and maintain systems |
| • covers your back | • it is very unusual for two organisations to work to the same standard or set of rules – does not improve inter-organisational communication |

PROJECT MANAGEMENT IN PRACTICE: **PRUDENTIAL CORPORATION ON THE MOVE**

The corporation left its ancestral home, 142 Holborn Bars, London, in 1988 in anticipation that the building would re-emerge after restoration and modernisation, stripped of its more arcane features, but retaining its Gothic fenestrated charm and tradition. Despite many false dawns, we have not been disappointed.

A successful move is built on a monument of planning activity. Equally true, as we have learned, this monument must be constructed like Lego, so that as expectations change or deadlines shift it can be quickly re-assembled in a different configuration.

Our planning process was based upon a top-level committee which contemplated an enormous variety of seriously important issues ranging from the colour of the carpet to the shape of the dining chairs and the location of the coffee machines. The committee was served by a professional project manager with the backing of a full-time team. However mundane each decision may appear, coordinating them is a task to rank with re-designing the space shuttle for complexity.

Clearly a move on this scale risked dislocating our business operations completely. We could scarcely close down our investment operations for a day to move the furniture or tell our customers their maturity cheques must wait until we found the crate containing the file.

Finally, it is worth remembering that however detailed the plans, some elements will inevitably escape, just as some carefully chosen furniture will look uncomfortable in its new home.

(*Source*: adapted from 'Tip from the Top: What about the Carpet Colour', Newmarch, M., Financial Times 22 November 1995 p. 11)

**SUMMARY OF KEY POINTS**

- the planning process must be managed as for other phases of project activity to maximise the value added by the process, and ensure that it does not become an organisational straitjacket, become hampered by over-attention to precision or overloaded with data;
- the purpose of the plan is to be both systematic and to be seen to be systematic;
- the planning process involves identifying activities, determining their logical sequence, estimating times and presenting the plan;
- the use of graphical techniques helps in the presentation of the plan and facilitates its review and revision;
- Gantt charts are a time-scaled graphical planning tool which give a static representation of the relationship between activities and their duration;
- network techniques provide a graphical means of expressing more complex projects and include activity-on-arrow (A-o-A) and activity-on-node (A-o-N) methods of representation of the verbal statement of activities;
- A-o-A activities move from left to right, and start and finish at an event with the arrow representing the activity;
- dummies are used to clarify the logic and preserve precedence relationships;
- critical path analysis allows determination of the path of activities, where, if there is any delay, the whole project will be delayed. The critical path should therefore be the initial focus for management attention;
- the critical path is determined by carrying out a forward pass through the diagram to establish the earliest event time (EET), then a reverse pass to establish the latest event time (LET);
- A-o-N facilitates the display of relationships other than simple precedence;
- PERT is a method which assesses the uncertainty of timing data and evaluates the optimistic, most likely and pessimistic times and allows a range or distribution of values to be considered;
- four field mapping is a technique which ensures that the relevant people are involved in the planning of activities, and places emphasis on managing information.

**KEY TERMS**

value-adding
precision and accuracy
data and information
tactical
operational
systematic
revision/refinement
forward/backward schedule
Gantt or linked bar chart
visibility
networks
activity-on-arrow/activity-on-node
dependency
dummies
critical path
earliest/latest event times
forward/reverse pass
slack
PERT
four fields mapping

# Reading

Meredith, J.R. and Mantel, S.J , Jr. (1995) *Project Management: A Managerial Approach*, 3rd Edition, John Wiley & Sons, Inc., pp. 389-403.

CHAPTER

# Resource Allocation

In the previous chapter we looked at a special type of resource allocation problem that of allocating time among project tasks better known as *scheduling*. Now we consider the allocation of physical resources as well. Also we are concerned with using resources in both individual and in multiple simultaneous projects. The subject relates directly to the topic of scheduling because altering schedules can alter the need for resources and—just as important—alter the timing of resource needs. At any given time the firm may have a fixed level of various resources available for its projects. The fixed resources might include labor-hours of various types of special professional or technical services, machine-hours of various types of machinery or instrumentation, hours of computing time, and similar scarce resources needed for accomplishing project tasks. For example, if the need for some resource varies between 70 and 120 percent of resource capacity, then that resource will be under utilized (and wasted if no alternative use exists) at one point in the project and in insufficient supply at another. If the project schedule can be adjusted to smooth the use of the resource, it may be possible to avoid project delay and, at the same time, not saddle the project with the high cost of excess resources "just to make sure."

This chapter addresses situations that involve resource problems. We discuss the trade-offs involved, the difference between allocation to one project and allocation between multiple projects, the relationship between resource loading and leveling, and some of the approaches employed to solve allocation problems, including the Critical Path Method (CPM) and several other well-known techniques. Although CPM is not actually a resource allocation method, we include it here because we view time as a resource, and trade-offs between time and other resources are a major problem in resource management. Finally, we note the major impact that current project management software has had on the PM's ability—and willingness—to deal with resource loading and leveling.

## 9.1 CRITICAL PATH METHOD

In Chapter 8 we mentioned that CPM is similar to PERT. In the original versions of CPM and PERT there was one important difference: CPM included a way of relating the project schedule to the level of physical resources allocated to the project. This allowed the PM to trade time for cost, or vice versa. In CPM, two activity times and two costs are specified, if appropriate, for each activity. The first time/cost combination is called *normal* and the second set is referred to as *crash*. Normal times are "normal" in the same sense as the *m* time estimate of the three times used in PERT. Crash times result from an attempt to expedite the activity by the application of additional resources—for example, overtime, special equipment, additional staff or material, and the like.

It is standard practice with PERT/CPM to estimate activity times under the assumption of resource loadings that are normal. To discuss a time requirement for any task without some assumption about the level of resources devoted to the task makes no real sense. At the same time, it does not make sense to insist on a full list of each and every resource that will be spent on each of the hundreds of activities that may comprise a PERT/CPM network. Clearly, there must have been some prior decision about what resources would be devoted to each task, but much of the decision making is, in practice, relegated to the common methods of standard practice and rules of thumb. The allocation problem requires more careful consideration if it is decided to speed up the accomplishment of tasks and/or the total project. We need to know what additional resources it will take to shorten completion times for the various activities making up the project.

While standard practice and rules of thumb are sufficient for estimating the resource needs for normal progress, careful planning is critical when attempting to expedite (crash) a project. Crash plans that appear feasible when considered activity by activity may incorporate impossible assumptions about resource availability. For example, we may need to crash some activities on the Wild Horse Dam Project. To do so, we have all the labor and materials required, but we will need a tractor-driven crawler crane on the project site not later than the eighth of next month. Unfortunately, our crane will be in Decatur, Illinois, on that date. No local contractor has a suitable crane for hire. Can we hire one in Decatur or Springfield and bring ours here?

And so it goes. When we expedite a project, we tend to create problems; and the solution to one problem often creates several more problems that require solutions.

Difficulties notwithstanding, the wise PM adopts the Scout's motto: "Be prepared." If deterministic time estimates are used, and if project deadlines are firm, there is a high likelihood that it will be necessary to crash the last few activities of most projects. Use of the three probabilistic time estimates of PERT may reduce the chance that crashing will be needed because they include uncertainties that are sometimes forgotten or ignored when making deterministic time estimates. Even so, many things make crashing a way of life on some projects—things such as last-minute changes in client specifications, without permission to extend the project deadline by an appropriate increment. An example of one of the problems that commonly result from the use of deterministic time estimates can be seen in the boxed example that follows.



### Architectural Associates, Inc.

Architectural Associates, Inc. (AAI) specializes in large, industrial, retail, and public projects, including shopping malls, manufacturing complexes, convention centers, and the like. The firm is considered to be one of the region's most effective and creative design studios. Their design facility is located in a large, midwestern city and is housed on the second floor of an old building, originally used for light manufacturing. The offices are at one end of the floor, and about two-thirds of the floor space is occupied by the design staff and technicians. The entire space devoted to design is a single, open area and workstations are laid out in such a way as to encourage communication between individuals working on a common project.

A senior executive of AAI noticed that, for the past year or two, the chance of bringing design projects in on time and on budget had decreased to the point where the only uncertainty was how late and how much over budget a project would be. Architectural projects, like computer programming and a few other creative processes, seem to be typified by the need to crash projects at the last minute, but even with the usual crash, AAI was still late and, consequently, over budget.

An examination of the workplace disclosed a large, green felt, display board mounted on the wall where it was visible to the entire design staff. The board listed the names of individual designers and technicians vertically, and design contract numbers across the horizontal axis. The times allocated for work on each project by appropriate staff members were shown at the intersections of the rows and columns. The time estimates were made by senior managers, themselves architects, based on their experience. The individuals with direct responsibility for design work generally felt that the time estimates were reasonable.

The work process was studied and the following problem was revealed. If the design of the electrical systems involved in a plan was estimated to take five days, for example, the individual(s) responsible for the work planned it in such a way that it used the five days allowed. If a problem occurred on the first day, the worker(s) simply stayed late or speeded up work the next day in order to get back on schedule. Problems on the second day, and even on the third and fourth days were handled in the same way, by crashing the work. Problems occurring on the fifth day, however, could not be handled so easily and this part of the project would be late. Because most of the different systems (the mechanicals, landscape, etc.) were designed simultaneously and staffed to require about the same number of days (rather than being sequential), and because problems were very likely to arise late in the design process of at least one of the systems, the overall design project, which required all tasks to be completed on time, was almost invariably late.

In an attempt to solve the problem, a simple check-mark to show job assignments was substituted for time allocations on the green board. Additionally, senior management made normal, optimistic, and pessimistic time estimates for each task and calculated "TE," also used to help estimate project cost. These estimates were not given to the design staff who were simply told to do the work involved as efficiently and effectively as they could. The result was that the range of task times increased slightly, but the average time required for the various tasks fell somewhat since they were now designed for efficiency rather than X days. Roughly the same number of tasks were accomplished in less than the expected time as tasks that took more than the expected time.

Consider the data in Table 9-1. First, we compute a cost/time *slope* for each activity that can be expedited (crashed). Slope is defined as follows:

$$\text{slope} = \frac{\text{crash cost} - \text{normal cost}}{\text{crash time} - \text{normal time}}$$

that is, the cost per day of crashing a project. The slope is negative, indicating that as the time required for a project or task is decreased, the cost is increased. Note that activity **c** cannot be expedited. Table 9-2 shows the time/cost slopes for our example.

A clear implication of this calculation is that activities can be crashed in increments of one day (or one period). Often, this is not true. A given activity may have only two or three technically feasible durations. The "dollars per day" slope of such activities is relevant only if the whole crash increment is useful. For example, if an activity can be carried out in either eight days or four days, with no feasible intermediate times, and if an uncrashable parallel path goes critical when the first activity is reduced from eight down to six days, then the last two days (to four days) of time reduction are useless. (Of course, there are times when the PM may expedite activities that have little or no impact on the network's critical time, such as when the resources used must be made available to another project.)

One must remember that crashing a project results in a change of the technology with which something is done. In the language of economics, it is a change in the "production function." At times, crashing may involve a relatively simple decision to increase groups of resources already being used. If the project, for instance, is to dig a ditch of a certain length and depth, we might add units of labor-shovel to shorten the time required. On the other hand, we might replace labor-shovel units with a Ditch Witch. Discontinuities in outcomes usually result. Different amounts of labor-shovel input may result in a job that takes anywhere from one to three days. Use of the Ditch Witch may require three hours. There may be no sensible combination of resources that would complete the job in, say, six hours. In some cases, technology cannot be changed, and task duration is fixed. A 30-day toxicity test for a new drug requires 30 days—no more, no less.

Not only do changes in technology tend to produce discontinuities in outcomes, they also tend to produce discontinuities in cost. As the technology is changed to speed a project, the cost curve relating input costs to time is apt to jump as we move from less to more sophisticated production systems. Not only is the curve displaced, it almost certainly will not be parallel to the earlier curve, but will change at a different rate. (For an extended treatment of this subject, see [37] (chapter 13)).

**Table 9-1** An Example of CPM

| Activity | Precedence | Duration, Periods (normal, crash) | Cost (normal, crash) |
|---|---|---|---|
| a | – | 3,2 | $ 40,80 |
| b | a | 2,1 | 20,80 |
| c | a | 2,2 | 20,20 |
| d | a | 4,1 | 30,120 |
| e | b | 3,1 | 10,80 |



**Table 9-2** Activity Slopes—Cost per Period for Crashing

| Activity | Slope ($/period) |
|---|---|
| a | 40/−1 = −40 |
| b | 60/−1 = −60 |
| c | — |
| d | 90/−3 = −30 |
| e | 70/−2 = −35 |

To use CPM, we develop a table or graph of the cost of a project as a function of the project's various possible completion dates. This can be obtained by either of two approaches.

The first approach is to start with the normal schedule for all project activities, and then to crash selected activities, one at a time, to decrease project duration at the minimum additional cost. This approach is illustrated in Figure 9-1. The normal schedule is shown in network 9-1a. (Note the required dummy activity. We use the AOA representation to illustrate that this procedure can be used with PERT as well as with CPM.)

The critical path of network 9-1 is **a–b–e.** To reduce the total network duration, we must reduce the time required by one of the activities along this critical path. Inspecting Table 9-2 to see which critical activity can be reduced at the least cost, we find it is **e,** at a cost of $35 per day. If we crash **e** by one day, we have a seven-day project duration at a cost of $155, as shown in Figure 9-1b.

Crashing **e** by a day has created a second critical path, **a–d–dummy.** To reduce project duration further, we might cut one day off this new critical path in addition to another day from activity **e.** (Remember that the path **a–b–e** is also critical.) Activity **d** has the most favorable cost-per-day rate among the critical activities. This adds $30 to the $35 required to reduce **e,** for a total cost increment of $65. We will still have two critical paths. Another alternative, however, is to crash an activity common to both critical paths, activity **a.** Reducing **a** by one day at a cost of $40 is less expensive than crashing both **e** and **d,** so this is preferred (see Figure 9-1c). Because **a** cannot be further reduced, we now cut **e** and **d** to lower total project duration to five days, which raises the project cost to $260 (see Figure 9-1d).

Activity **e** has now been crashed to its maximum (as has **a**), so additional cuts will have to be made on **b** to reduce the **a–b–e** critical path. Cutting one day from **b** (which is expensive) and **d** results in the final network that now has a time of four days and a cost of $350, more than 200 percent of the cost for normal time. The project duration cannot be reduced further, since both critical paths have been crashed to their limits.

The second approach to CPM is to start with an all-crash schedule, compute its cost, and "relax" activities one at a time. Of course, the activities relaxed first should be those that do not extend the completion date of the project—that is, those not on the critical path. In our example, this is possible. The all-crash cost is $380, and the project duration is four days. Activity **d,** however, could be extended by one day at a cost saving of $30 without altering the project's completion date. This can be

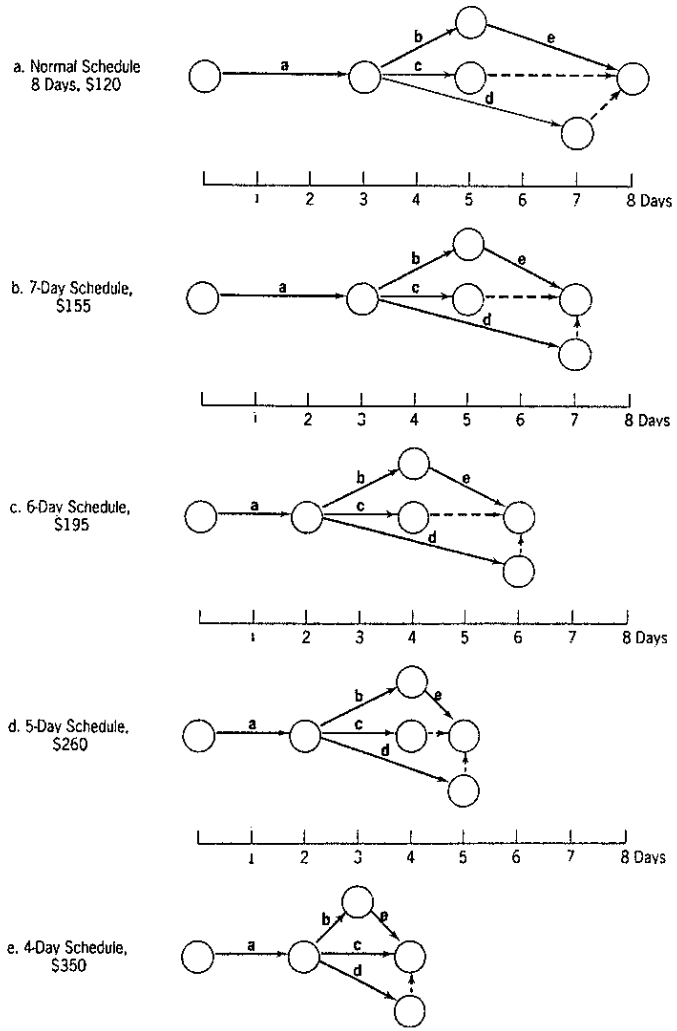



***Figure* 9-1:** A CPM example.

seen in Figure 9-1e, where activity **d** is shown taking two days. Continuing in this manner would eventually result in the all-normal schedule of eight days and a cost of $120, as shown in Figure 9-1a.

The time/cost relationships of crashing are shown in Figure 9-2. Starting at the right (all-normal), note that the curve of cost per unit of duration gets steeper and



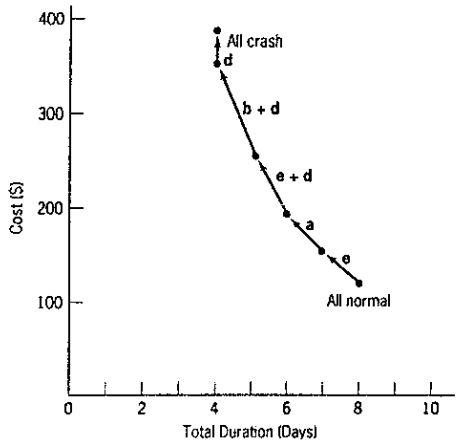



***Figure* 9-2:** CPM cost-duration history.

steeper the more the project duration is reduced. It becomes increasingly costly to squeeze additional time out of the project. Economists will recognize that attempts to expedite a project are subject to decreasing marginal returns.

Charts such as the one shown in Figure 9-2 are useful to the PM in exercising control over project duration and cost. They are particularly helpful in dealing with senior managers who may argue for early project completion dates with little understanding of the costs involved. Similarly, such data are of great benefit when clients plead for early delivery. If the client is willing to pay the cost of crashing, or if the firm is willing to subsidize the client, the PM can afford to listen with a sympathetic ear. (While we advise the PM to ignore overhead cost over which he/she has no control, it should be noted that indirect costs are often altered when a project is crashed.)

Some organizations have more than one level of crashing. Table 9-3 illustrates such a case. In this example, the firm has two distinct levels of expediting a project, rush and blitz. The differences in the precedence relationships between tasks are noted in the table, as are differences in resource commitments. The last two rows of the table show the expected changes in cost and time if the project is expedited.

Finally, if a project has a penalty clause that makes the organization liable for late delivery, the cost/duration trade-off curve contains the information the PM needs to know in order to determine whether crashing the project or paying the penalty is the more economic course of action.

## 9.2 THE RESOURCE ALLOCATION PROBLEM

A shortcoming of the scheduling procedures covered in the previous chapter is that they do not address the issues of resource utilization and availability. They focus on time rather than physical resources. Also, in the discussion that follows it will not

**Table 9-3** Official Pace of a Project

| Title | Normal | Rush | Blitz |
|---|---|---|---|
| Approved Project Definition | Full | Some abbreviations from normal pace. | Only as necessary for major management decisions, purchasing and design engineering. |
| Study of Alternates | Reasonable | Quick study of major profitable items. | Only those not affecting schedule. |
| Engineering Design | Begins near end of Approved Project Definition. | Begins when Approved Project Definition 50–75% complete. | Concurrently with such Approved Project Definition as is done. |
| Issue Engineering to Field | Allow adequate time for field to plan and purchase field items. Usually 1/2–2 months lead time between issue and field erection. | Little or no lead time between issue and field erection. | No lead time between issue and field erection. |
| Purchasing | Begins in latter stages of Approved Project Definition. | Done concurrently with Approved Project Definition. Rush purchase of all long delivery items. Many purchases on "advise price" basis. | Done concurrently with such Approved Project Definition as is done. Rush buy anything that will do job. Overorder and duplicate order to guarantee schedule. |
| Premium Payments | Negligible | Some to break specific bottlenecks. | As necessary to forestall any possible delays. |
| Field Crew Strength | Minimum practical or optimum cost. | Large crew with some spot overtime. | Large crew; overtime and/or extra shifts. |
| Probable Cost Difference Compared with Normal Pace, as a Result of: | | | |
| *Design and Development | Base | 5–10% more | 15% and up, more |
| *Engineering and Construction costs | Base | 3–5% more | 10% and up, more |
| Probable Time | Base | Up to 10% less | Up to 50% less |

be sufficient to refer to resource usage simply as "costs." Instead, we must refer to individual types of labor, specific facilities, kinds of materials, individual pieces of equipment, and other discrete inputs that are relevant to an individual project but are limited in availability. Last, we must not forget that time itself is always a critical resource in project management, one that is unique because it can neither be inventoried nor renewed.



The relationship between progress, time, and resource availability/usage is the major focus of this chapter. Schedules should be evaluated not merely in terms of meeting project milestones, but also in terms of the timing and use of scarce resources. A fundamental measure of the PM's success in project management is the skill with which the trade-offs among performance, time, and cost are managed. It is a continuous process of cost–benefit analysis: "I can shorten this project by a day at a cost of $400. Should I do it?" "If I buy 300 more hours of engineering time, I may be able to improve performance by 2 or 3 percent. Should I do it?"

Occasionally it is possible that some additional (useful) resources can be added at little or no cost to a project during a crisis period. At other times, some resources in abundant supply may be traded for scarce ones (á la M.A.S.H.'s "Radar"). Most of the time, however, these trades entail additional costs to the organization, so a primary responsibility for the PM is to make do with what is available.

The extreme points of the relationship between time use and resource use are these:

- ***Time Limited:*** The project must be finished by a certain time, using as few resources as possible. But it is time, not resource usage, that is critical.
- ***Resource Limited:*** The project must be finished as soon as possible, but without exceeding some specific level of resource usage or some general resource constraint.

The points between these two extremes represent time/resource-use trade-offs. As in Figure 9-2, they specify the times achievable at various resource levels. Equivalently, they specify the resources associated with various completion times. Clearly, the range of time or resource variability is limited.

Occasionally, both time and resources may be limited, but in this case, the specifications cannot also be fixed. If all three variables—time, cost, specifications—are fixed, the system is "overdetermined." The PM has lost all flexibility to perform the trade-offs that are so necessary to the successful completion of projects. Of course, it is possible that all three variables might be fixed at levels that allowed the PM plenty of maneuvering room, but this is most unlikely. Far more likely, our project manager acquaintances tell us, is the case in which senior management assigns budgets, schedules, and specifications without regard for the uncertainties of reality. It is the PM's responsibility, possibly with help from the project's champion, to warn senior management of the impropriety of such restrictions in spite of the chance that a senior manager might respond with "I'll get someone who can. . . !"

On occasion, it may be that one or more tasks in a project are *system-constrained*. A system-constrained task requires a fixed amount of time and known quantities of resources. Some industrial processes—heat treating, for instance—are system-constrained. The material must "cook" for a specified time to achieve the desired effect. More or less "cooking" will not help. When dealing with a system-constrained task or project, no trade-offs are possible. The only matter of interest in these cases is to make sure that the required resources are available when needed.

In the following sections we discuss approaches for understanding and using these relationships in various project situations.

## 9.3 RESOURCE LOADING

*Resource loading* describes the amounts of individual resources an existing schedule requires during specific time periods. Therefore, it is irrelevant whether we are considering a single work unit or several projects; the loads (requirements) of each resource type are simply listed as a function of time period. Resource loading gives a general understanding of the demands a project will make on a firm's resources. It is an excellent guide for early, rough project planning. Obviously, it is also a first step in attempting to reduce excessive demands on certain resources, regardless of the specific technique used to reduce the demands. Again, we caution the PM to recognize that the use of resources on a project is often nonlinear. Much of the project management software does not always recognize this fact [20].

The PERT/CPM network technique is well suited for the job of generating time-phased resource requirements. A Gantt chart could be adapted, but the PERT/CPM diagram, particularly if modified to illustrate slacks, will be helpful in the analysis used for resource leveling. Let us illustrate with the PERT/CPM network used as an example in the previous chapter. The network (Table 8-2) reappears as Figure 9-3, and resource usage is illustrated for two hypothetical resources, A and B, on the arcs. The expected activity time is shown above the arc and resource usage is shown in parentheses just below the arc, with the use of A shown first and B second—e.g., (5,3) would mean that five units of A and three units of B would be used on the activity represented by the arc. Figure 9-4 shows the "calendarized" PERT/CPM diagram, similar to the familiar Gantt chart. Resource demands can now be summed by time period across all activities.

The loading diagram for resource A is illustrated in Figure 9-5a, and that for resource B in Figure 9-5b. The loads are erratic and vary substantially over the duration of the project. Resource A, used in tasks **a**, **b**, and **c**, has a high initial demand that drops through the middle of the project and then climbs again. Resource B, on the other hand, has low initial use but increases as the project develops. The PM must be aware of the ebbs and flows of usage for each input resource throughout

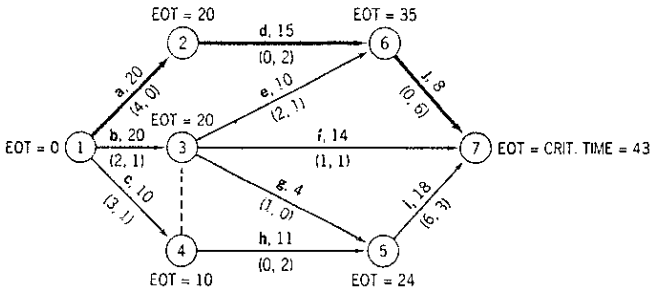



*Figure* 9-3: The complete network from Figure 8-15.



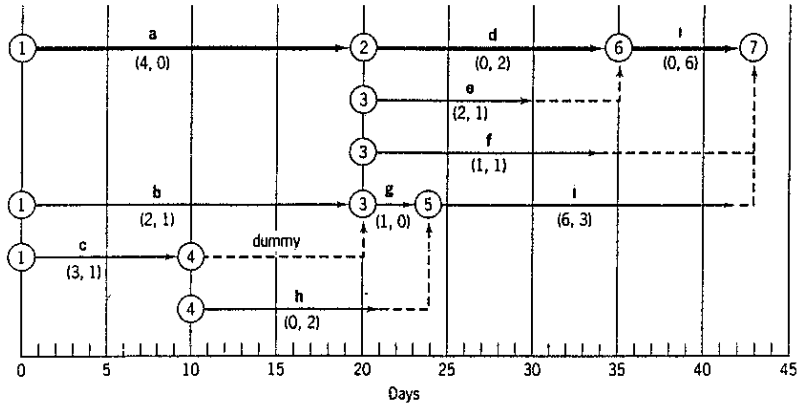



*Figure* 9-4: Modified PERT/CPM diagram showing resource usage (from Figure 9-3).

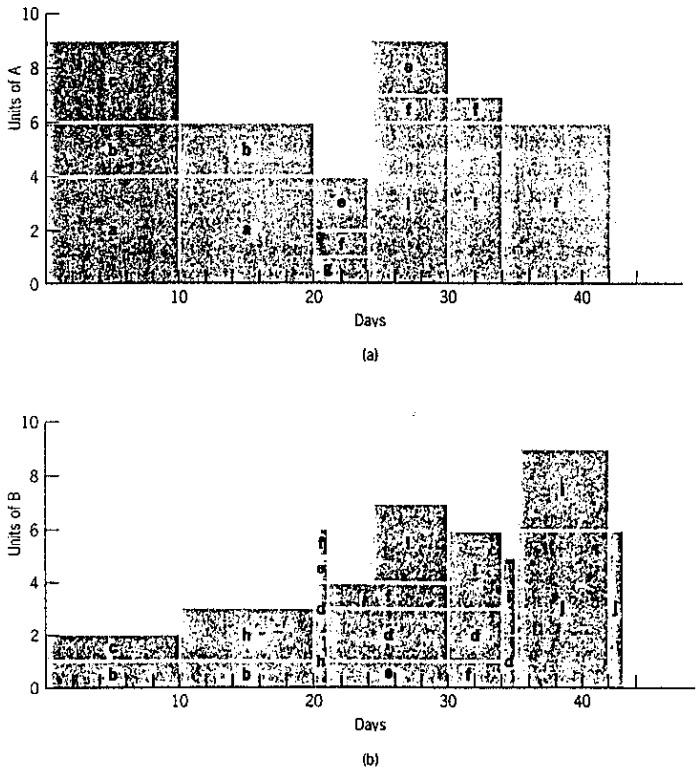



*Figure* 9-5*a*: Load diagram for resource A. *b*: Load diagram for resource B.

the life of the project. It is the PM's responsibility to assure that the required resources, in the required amounts, are available when and where they are needed. In the next three sections, we will discuss how to meet this responsibility.

## 9.4 RESOURCE LEVELING

In the example above, we noted that the project began with the heavy use of resource A, used smaller amounts during the middle of the project, and then continued with rising usage during the project's latter stages. Usage of B started low and rose throughout the project's life. Large fluctuations in the required loads for various resources are a normal occurrence—and are undesirable from the PM's point of view. Resource leveling aims to minimize the period-by-period variations in resource loading *by shifting tasks within their slack allowances*. The purpose is to create a smoother distribution of resource usage.

There are several advantages to smoother resource usage. First, much less hands-on management is required if the use of a given resource is nearly constant over its period of use. The PM can arrange to have the resource available when needed, can have the supplier furnish constant amounts, and can arrange for a backup supplier if advisable. Moreover, the PM can do this with little error. Second, if resource usage is level, the PM may be able to use a "just-in-time" inventory policy without much worry that the quantity delivered will be wrong. If the resource being leveled is people, leveling improves morale and results in fewer problems in the personnel and payroll offices because of increasing and decreasing labor levels.

Not only are there managerial implications to resource leveling, there are also important cost implications. When resources are leveled, the associated costs also tend to be leveled. If resource use increases as time goes by, and if resources are shifted closer to the present by leveling, costs will be shifted in the same way. The opposite is true, of course, if resource usage is shifted to the future. Perhaps most important from a cost perspective is leveling employment throughout a project or task. For most organizations, the costs of hiring and layoff are quite significant. It is often less expensive to level labor requirements in order to avoid hiring and layoff even if it means some extra wages will be paid. In any case, the PM must be aware of the cash flows associated with the project and of the means of shifting them in ways that are useful to the parent firm.

The basic procedure for resource leveling is straightforward. For example, consider the simple network shown in Figure 9-6a. The activity time is shown above the arc, and resource usage (one resource, workers) is in parentheses below the arc. Activities **a**, **b**, and **c** follow event 1, and all must precede event 4. Activity **a** requires two workers and takes two days, **b** requires two workers and takes three days, and **c** needs four workers and five days. (We addressed the problem of trade-offs between labor and activity time in the first section of this chapter.) If all these tasks are begun on their early start dates, the resource loading diagram appears as shown in Figure 9-6b, steps of decreasing labor demand varying from eight workers to four workers. If, however, task **b** is delayed for two days, the full length of its slack in this particular case, the resource loading diagram is smoothed, as shown in Figure 9-6c.



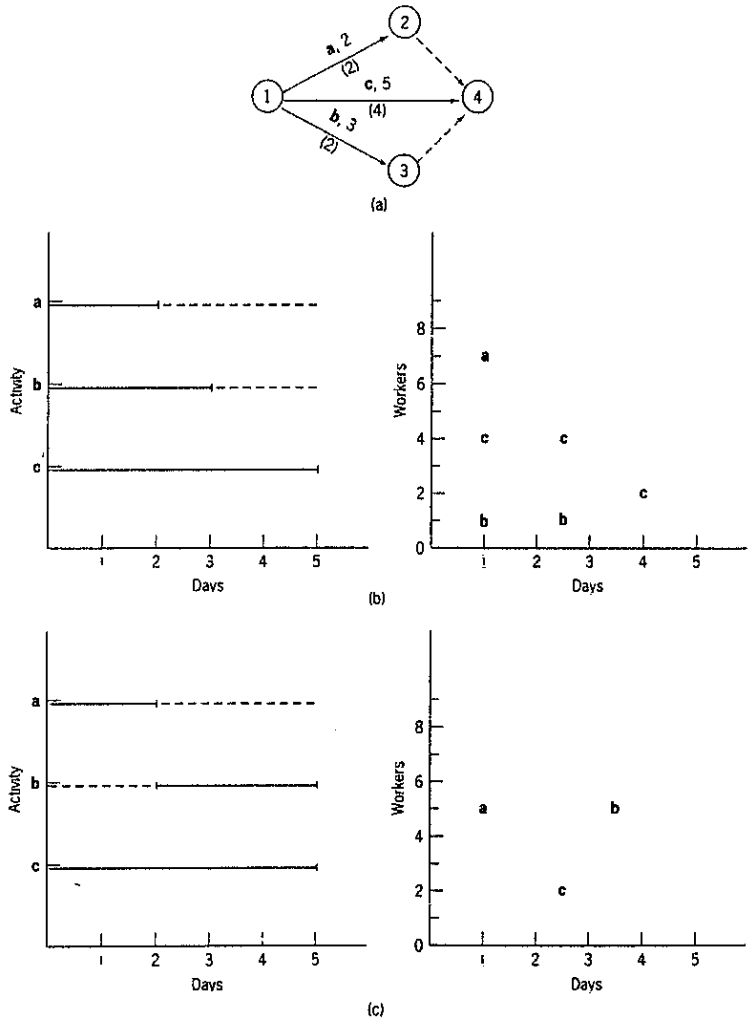



*Figure 9-6a*: The network. *b*: Before resource leveling. *c*: After resource leveling.

The same result would have occurred if **b** were started as early as possible and task **a** were delayed until day 3.

Resource leveling is a procedure that can be used for almost all projects, whether or not resources are constrained. If the network is not too large and there are only a few resources, the leveling process can be done manually. For larger networks and multiple resources, resource leveling becomes extremely complex, far be-

# Reading

Oxley, R. and Poskitt, J. (1996) *Management Techniques Applied to the Construction Industry*, 5th Edition, Blackwell Science Ltd., pp. 1-24.

Chapter 1

# Construction Planning and Control

## 1.1 Introduction

Planning can be applied in varying degrees of detail, depending on the stage at which it is being carried out For construction work it is usually divided into *pre-tender planning*, *pre-contract planning* and *short-term planning*.

Examples of the use of planning and control at all stages of a project are shown in the case studies in Chapter 7.

### 1.1.1 *Pre-tender planning*

Pre-tender planning is undertaken to allow the estimator to arrive at an estimate of cost, based on the proposed methods of working and an estimate of the time required to carry out the major operations Programming at the pre-tender stage is usually in an outline form on large projects, to consider only the phasing of the main operations, as much information is not available at that time.

### 1.1.2 *Pre-contract planning*

Pre-contract planning is carried out when the contract has been won, and the project is considered more fully. Planning at this stage includes the master programme, labour schedule, plant schedule, and materials schedules. The master programme should not break the operations down excessively on large projects or it will become unrealistic.

The information to be used as a basis for calculating productive hours at this stage can be obtained from operational records of past contracts and from the bill of quantities, provided it is accurate. If the bill is employed, many items will have to be collected together under the

heading of the programme operations (for example, the operation 'brickwork' will include such items as 'plain bands' and 'damp-proof courses').

The bill rates should be broken down to show labour and plant content so that the labour and plant content of operations can be easily ascertained.

#### 1.1.3 *Short-term planning*

Short-term planning is carried out in greater detail, and the programmes at this stage are broken down much further.

Short-term programming can cover a period of four to six weeks, or may cover a stage of the work. For six-week programmes a new programme is drawn up every fourth week, thus providing a two-week overlap and allowing a review to be made of the work outstanding from the previous month; any work behind schedule can then be included in the current programme.

The purpose of short-term planning is to ensure that work proceeds in accordance with the overall programme, which must be updated regularly, while a review is simultaneously made of all requirements by checking schedules.

The most suitable time for preparation of the programme is after the monthly planning meeting, which is in turn best held immediately after the Architect's monthly meeting. In this way account can be taken of any alterations or variations that are necessary.

The basis of calculations at this stage can be the bill of quantities, combined with operational records. Work study synthetics can be useful if available. There should be an integrated cost control/bonusing/planning and surveying system, which will provide the basic information for all departments. The expected outputs for bonus operations should be used in calculating the time required.

#### 1.1.4 *Control of progress on site*

Control must be carried out to make planning effective, as without control planning loses much of its value. It must be applied continuously to update the plans, and to enable reconsideration of the workload in the light of what has already taken place.

Control involves comparing, at regular intervals, the actual achievement with the plans and then taking any necessary corrective action to bring operations back on schedule.



If a programme is to be really effective as a control document, it must represent time and quantity of work carried out. This is particularly important on programmes where operations take several weeks or months to perform, as time alone will not clearly indicate whether work in progress is behind programme or not.

Progress can be recorded on planning charts that clearly indicate what is happening and where corrective action needs to be taken. Another method is to use pictorial diagrams, by colouring plans and elevations when certain sections of work are completed,. This method is often used on housing projects, and provides a visual impression of overall progress, but other ways are also available depending on the type of building and the amount of detail necessary.

#### 1.1.5 *Use of meetings*

Monthly and weekly meetings are invaluable in helping to control progress. The work that is not proceeding as planned will receive particular attention, and explanations will be required where sufficient progress is not being achieved. The action necessary for correcting underproduction will be considered, and the best solution will then be incorporated into the programme for the next period.

## 1.2 Bar charts

#### 1.2.1 *Introduction*

Bar charts are far less involved than network charts, and are particularly useful for small projects. Many contractors use bar charts for all their programmes, although there is an ever-increasing tendency for architects and engineers to request network presentation, either by asking for networks specifically or by asking for information that is best produced using networks: for example, requests to show critical activities and float.

In examination conditions, bar chart programmes may be the only reasonable method of presentation, because the alternative would necessitate drawing a network, analysing it, and then scheduling the project, which would involve resource allocation. This may then have to be adjusted to bring the project within the allowed duration. Consequently, unless a network is specifically requested in an examination, bar chart presentation would be more logical.

### 1.2.2 *Drawing bar charts*

As the name implies, bars are used to represent the duration over which an operation is planned to take place. They are also used to record the period over which the operation was carried out.

**Example 1.1: Roadworks project**

As an illustration, a roadworks project for a housing scheme will be used as follows:

Contract period 18 weeks

- *Clear site*
  - Commence beginning on week 1.
  - Complete end of week 3.
- *Site excavations*
  - Commence beginning of week 1.
  - Complete end of week 6.
- *Sewers*
  - Commence beginning on week 3.
  - Complete end of week 14.
- *Surface water drains*
  - Commence beginning on week 3.
  - Complete end of week 15.
- *Concrete road*
  - Commence beginning on week 6.
  - Complete end of week 16.

A bar chart programme for the project is shown in Fig. 1.1.

The duration of each operation must of course be realistic, and is best obtained from production data. This is clearly illustrated in the case studies in Chapter 7.

### 1.2.3 *Showing progress on bar charts*

The bars on the chart in Fig. 1.1 represent the duration of the operations, but they can also represent the quantity of work to be done: that is, the bar represents 100% of the work involved in the operation. By exploiting this, the chart can be used to present a considerable amount of information during the progress of the works.



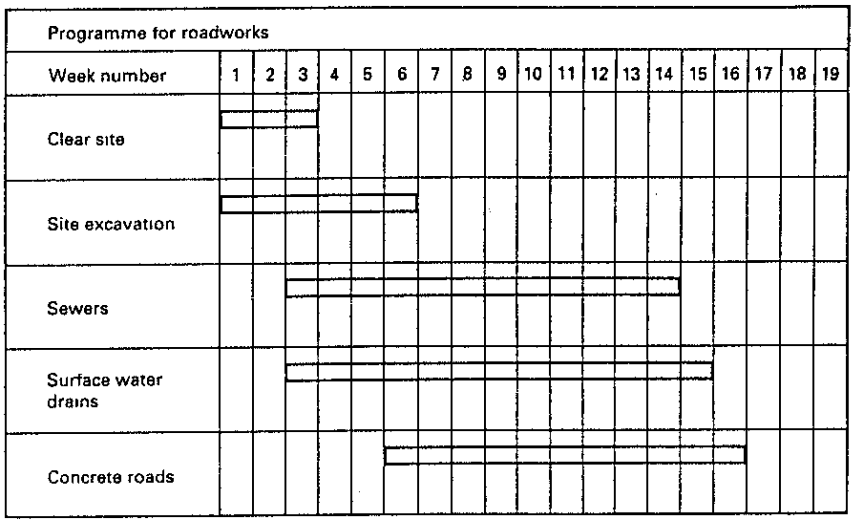



Fig. 1.1 Bar chart programme for housing scheme roadworks project.

**Example 1.2: Roadworks project progress**

As an example, assume that at the end of week 5, progress was as follows:

- Clearing site commenced halfway through week 1 and was completed halfway through week 4.
- Site excavation commenced halfway through week 1 and is 70% complete.
- Sewers commenced at the beginning of week 3 and are 20% complete.
- Surface water drains commenced halfway through week 3 and are 30% complete.
- Concrete road has not yet started.

This information can be shown on the chart, as shown in Fig. 1.2. The representation of the quantity of work done is calculated as follows:

- Site excavation 70% of 6 = 4.2 weeks' work
- Sewers 20% of 12 = 2.4 weeks' work
- SW drains 30% of 13 = 3.9 weeks' work

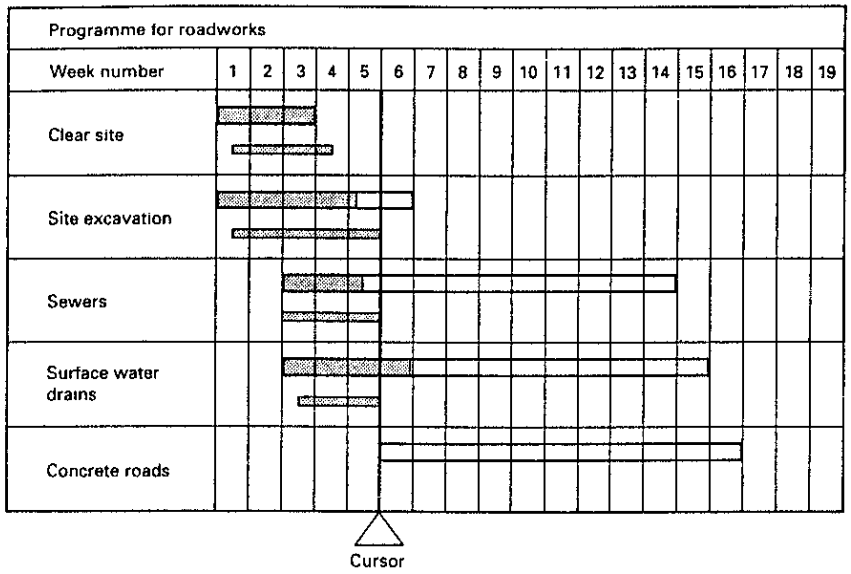



Fig. 1.2 Roadworks project: progress at end of week 5.

The information presented can be summarised as follows:

- *Clear site*: commenced half a week late and completed half a week late. It took the amount of time programmed.
- *Site excavation*: Commenced half a week late, is still proceeding and is now 0.6 weeks behind programme. At the present rate it will finish 1 week behind programme.
- *Sewers*: commenced on time and is now 0.6 weeks behind programme. At the present rate of progress it will finish 3 weeks late. Transfer operatives from surface water drains (or increase the labour strength by 25%).
- *SW drains*: commenced 0.5 weeks late but is now 0.8 weeks in front. At the present rate of progress it will finish 4.67 weeks in front of programme. Transfer some resources to sewers.
- *Concrete road*: not yet started. Start next Monday.



## 1.3 Method statements

### 1.3.1 *Introduction*

Method statements may be drawn up at any stage of a project. The extent of detail is determined by the purpose of the method statement and the stage at which it is being drawn up. For example, at the pre-tender stage, decisions need to be taken on major plant to be used and the methods to be used for major operations. At the detailed planning stage, method statements would be in much more detail.

Consideration of the methods is essential before programming is carried out, as this clearly affects the operation durations.

Method statements are best presented on a standard form, and should include as much information as is appropriate to the stage at which they are being drawn up. An example of the information that might be required is as follows:

- a heading for the item being described
- description of method
- quantity if appropriate
- plant and equipment
- gang sizes if appropriate
- output if appropriate
- duration if appropriate.

Sometimes cost is added, but this cannot be ascertained for non-continuous operations involving plant until a programme is drawn up.

Whenever possible, the prospective site manager would be involved in determining methods.

Questions similar to those asked in the examination stage of work study should be asked before decisions are taken:

- What should be done?
- Where should it be done?
- When should it be done?
- Who should do it?
- How should it be done?

### 1.3.2 *Pre-tender method statement*

This is one of the most important pre-tender documents, because it is used by the estimator as the basis for arriving at the cost of many of the

major items of work. It follows that the method statement should include all work of any consequence where alternative methods or choice of plant are possible.

The method statement takes the form of a schedule (see Fig. 1.3) stating the method to be adopted or plant to be used for such activities as excavation, formwork, and concreting. It is compiled at the same time as the pre-tender programme and site layout drawing, after the estimator has considered each problem in detail and has arrived at the best solution with regard to resources required and cost. Having arrived at the resources required, it is common practice to record these in the schedule for future reference. Together with the pre-tender programme it forms the basis for the overall programme. The schedule is also very useful for informing site staff of the method that the estimator has used when arriving at a price.

Pre-tender method statement
Office block, Manchester Road, Sheffield Date:

| Item | Quantity | Remarks | Labour and plant | Time required |
|---|---|---|---|---|
| Excavation | 110m³ | Reduced level dig – Front bucket of JCB Sitemaster – easy going | JCB Sitemaster operator 3 labourers | 1 day |
| | 135m³ | Ground beam trenches – Rear backacter bucket of JCB Sitemaster<br>Internal drain trenches – Rear backacter bucket of JCB Sitemaster | JCB Sitemaster operator 3 labourers | 1 week |
| | | Disposal of surplus spoil – Remove to tip 2 miles | 3 lorries 2 drivers | 1 week |
| General hoisting and transportation | | 750 kg platform hoist placed adjacent to front entrance | 750 kg platform hoist | 15 weeks |
| Concreting | 98m³ | Ready mixed concrete | | |
| | 98m³ | Transportation – Placed directly into trenches for foundations. Placed directly into GF slab using hit and miss method of construction | Ready mix lorry | |
| | | Mobile crane for first floor | Lorry mounted mobile crane | 1 day |
| | 98m³ | Placing – Poker vibrators for foundations and ground beams. Vibrating screed for all slabs | Vibrating pokers<br>Vibrating screed | 1 week<br>GF – 1 week FF – 1 week |

Fig. 1.3 Part of a pre-tender method statement.



Time spent in the preparation of a well-thought-out method statement usually results in a more competitive tender, and when considered with a programme it can result in the solution of some potential problems before they arise.

Part of a pre-tender method statement is shown in Fig. 1.3.

### 1.3.3 *Detailed method statement*

Method statements can be compiled along with stage or short-term programmes, recording in detail the methods selected for completing a particular stage of the work on a project. The information in this type of method statement would be primarily for the benefit of the site staff, but it could be fed back to the estimator for his future reference.

Part of a detailed method statement is shown in Fig. 1.4.

Detailed method statement
Amenity centre, Bradford

| Item | Quantity | | Method | Output | Plant | Labour | Time required |
|---|---|---|---|---|---|---|---|
| Underpinning | 40 piles | 1 | Piles driven 2 m from face of existing building | – | Sub-contract | | 5 days |
| | 30 m³ | 2 | Excavate preliminary trench down to base of existing foundation by hand-excavated material deposited at side of trench | 1 h/m³ | | | |
| | 150 m³ | 3 | Excavate trenches in short lengths to 600 mm below level of column bases in basement. Wall divided into six equal sections and sequence of excavation to be (1 and 10), (3 and 7), (5), (2 and 8), (4 and 6). Sections being excavated not to exceed quarter of length of wall at any time | 5 h/m³ | | 3 labs | 32 days |
| | 54 m² | 4 | Support to side of excavation under building to be provided by precast concrete slabs as work proceeds, grouted up at back and left in-strutted off sheet piles | 1 h/m² | | | |
| | 6 m³ | 5 | Concrete to foundations to be mixed on site and to be rebated at both ends | Mixer 1 h/m³ | 150/100 mixer | | |
| | 45 m² | 6 | Brickwork to underside of existing foundation to be toothed both sides | 40 bks/h | 150/100 mixer | 1 blr 1 lab | |
| | | 7 | Weak concrete fill to back of wall as brickwork proceeds | To keep pace with Op. 6 | 150/100 mixer | 1 blr 1 lab | 31 days |
| | 3 m² | 8 | Pin up brickwork | 7.5 h/m² | | 1 blr 1 lab | |
| | 1.5 m³ | 9 | Back off existing foundations | 15 h/m³ | Compressor 2 No drills | 3 labs | 1 day |
| Basement excavation | 84 piles | 10 | Piles driven around basement, 600 mm outside outer face of wall on NW, SW and SE sides | | Sub-contract | | 12 days |
| | 545 m³ | 11 | Commence excavation at SW side of site and work back towards car park. Dispose of all excavated material to tip. Compact bottom of excavation using plate vibrator | 0.1 h/m³ | JCB Sitemaster 3 No 4 m³ lorries | 3 labs | 7 days |

Fig. 1.4 Part of a detailed method statement.

#### 1.3.4 *Further examples of method statements*

Further examples of method statements are shown in the case studies in Chapter 7.

## 1.4 Sequence studies

#### 1.4.1 *Introduction*

It is necessary to compile sequence studies when closely related operations have to be coordinated: for example, the construction of the columns, beams and slabs in a reinforced concrete framed building, or the finishing trades in a building such as a multi-storey office block, which would have much repetitive work on the various floors.

#### 1.4.2 *Achieving continuity*

To achieve continuity of work throughout these repetitive cycles, it is necessary to balance the gangs of workmen.

**Example 1.3: Procedure for preparing a sequence study**

Assume the frame of a 12-storey reinforced concrete building is to be erected and the work content per floor is as follows:

- *Columns and walls*
  - reinforcement 128 man-hours
  - concreting 20 man-hours
  - formwork 512 man-hours
- *Floors (including beams and slab)*
  - reinforcement 160 man-hours
  - concreting 80 man-hours
  - formwork 640 man-hours

An 8 hour day is used in the calculations. The hardening period for columns and walls is 2 days and for floors and beams 7 days, the props being left in. The preparation of the sequence study is then carried out as follows:



(1) Calculate the work content of steelfixers and carpenters

| | *Reinforcement* | *Formwork* |
|---|---|---|
| Columns and walls | 128 | 512 |
| Floors | 160 | 640 |
| Total | 288 | 1152 |

(2) Balance the gangs

Ratio of carpenters to steelfixers $\frac{1152}{288} = 4 : 1$

Therefore use 8 carpenters and 2 steelfixers (could have used other combinations giving a 4 : 1 ratio).

*Note*: Concrete gang will be used intermittently as required and will be working on other operations when not required on the frame.

The sequence will be arranged to reuse formwork as much as possible. In this example sufficient formwork for one complete floor will be required.

(3) Calculate operations times:

Time required for columns and walls:

reinforcement $\frac{128}{2 \times 8} = 8$ days (half floor = 4 days)

formwork $\frac{512}{8 \times 8} = 8$ days – assume 6 erect and 2 strip (half floor assume 3 erect and 1 strip)

Time required for floors and beams:

reinforcement $\frac{160}{2 \times 8} = 10$ days

formwork $\frac{640}{8 \times 8} = 10$ days – assume $7\frac{1}{2}$ erect $2\frac{1}{2}$ strip (half floor asume $3\frac{3}{4}$ erect $1\frac{1}{4}$ strip)

(4) Prepare the sequence study providing continuity on the repetitive work cycles on each floor (see Fig. 1.5). Of the three trades involved, the carpenters have the least flexibility because all their work takes place on the building itself. Steelfixers have a reasonable amount of flexibility because they can fabricate columns and beams when they are not actually fixing steel in position. When sufficient column cages have been erected it is possible to start the formwork, and care must be taken to allow the required hardening periods before the various formwork elements are stripped. The sequence of formwork erection and stripping is shown in Fig. 1.5.

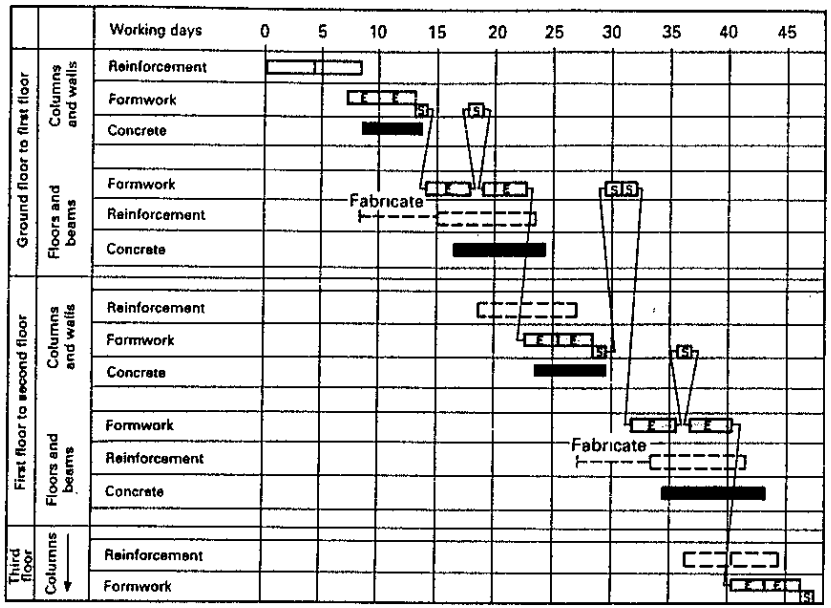



Fig. 1.5 Sequence study: formwork erection and stripping.

As the formwork and steelfixing gangs have been balanced it is not necessary to show the fixing of steel in great detail, but merely to indicate the period over which it would be carried out. As stated previously, the concrete would be placed intermittently as required.

If more detailed planning is to be carried out, this would take place at the short-term planning stage.

## 1.5 Site layout

The physical factors of the site often affect the method and sequence adopted in the construction programme, so the programme and the site layout are usually prepared together.

### *1.5.1 Factors affecting site layout*

Before attempting to construct a site layout drawing, a list should be compiled of all accommodation, plant and material storage areas



required. The areas on site that are available to the contractor should then be investigated to assist in determining the overall arrangement of the items mentioned above. For example, where would the staff accommodation or the major items of plant be best situated? This should be considered in overall terms at an early stage, followed by a consideration of the more detailed aspects of the site layout.

For this work a detailed site drawing is necessary to a scale of at least 1 : 100, showing all foundations, drains, and any other features that could affect the layout. The most suitable drawings are usually the site general arrangement, the ground-floor plan and any other drawing that gives the full extent of the site and shows all obstructions. As changes will be made frequently in arriving at the site layout, two common methods may be used to facilitate alterations:

- The scale drawing can be overlaid with a sheet of clear plastic on which the planner will draw his tentative layout with a wax crayon, which can easily be erased if parts of the layout are later found to be unsuitable.
- Silhouettes or models of all items of accommodation, plant and storage areas are produced to the same scale as the layout drawing, and placed on the scale drawing in the areas set aside for particular activities. They can then be moved around until the required layout is achieved. This method is a work study technique, which is very useful in obtaining the best layout.

Temporary roads may or may not be necessary, depending upon the type of subsoil experienced on site. When they *are* used they should be planned to serve all major items of plant and material storage compounds; hardcore or railway sleepers may be employed as construction material. In some cases the site service roads may be completed before building work commences, in which case they could be used to provide access about the site.

A number of factors can influence the location of accommodation, plant, storage areas and temporary roads, and these are considered in the example of a site layout shown in the case studies in Chapter 7.

## 1.6 The line of balance method (elemental trend analysis)

### *1.6.1 The advantages of the method*

One of the main advantages of this method is that it gives a better indication of the dependence of one activity on another. It is very useful

when progressing because it is immediately obvious when corrective action needs to be taken.

**Example 1.4: Use of line of balance method**

Normally the line of balance method is used only when large numbers of units are to be built, but in order to illustrate the method a smaller project will be used.

Assume that ten identical units are to be constructed. The work content and sequence for some of the internal activities is shown in Table 1.1. No overlap is to be used between units. A 5 day week is to be worked.

**Table 1.1** Work content and sequences.

| Activity | Time required |
|---|---|
| Plumbing carcass | 4 gang-days |
| Electrical carcass | 3 gang-days |
| Carpenter first fix | 2 gang-days |
| Plastering | 4 gang-days |
| Plumbing sanitary fittings | 3 gang-days |
| Electrical fittings | 1 gang-day |
| Carpenter second fix | 5 gang-days |

In all types of repetitive construction, it is necessary to balance the gangs of operatives if non-productive time and project duration are to be kept to a minimum.

To illustrate this point, assume a line of balance schedule is prepared using one gang on each activity. Each gang is to be continuously occupied once they start on site, and no buffer is to be used between the activities. The line of balance schedule would be as shown in Fig. 1.6. It is clear that the project duration is excessive, which results in high overhead costs.

If a schedule is produced using one gang on each activity, as in Fig. 1.6, but starting each activity as soon as the previous one is completed on each unit, the line of balance schedule would be as shown in Fig. 1.7. This would reduce the project duration, but would result in excessive non-productive time, which in turn would result in high direct costs.

In order to prepare a schedule to give continuity of work and to complete the project in reasonable time, more gangs would be required. To clarify the method it is assumed that the completion rate for each unit is to be one per day. The number of gangs required to achieve this is shown in Table 1.2.



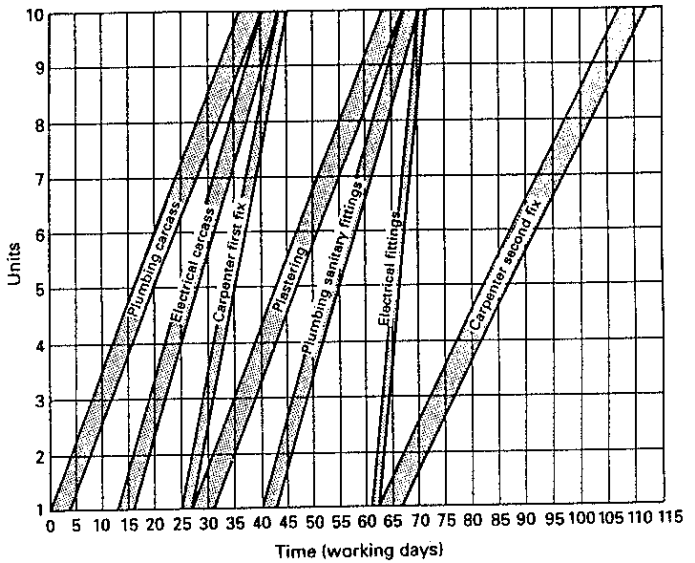



Fig. 1.6 Line of balance schedule: high overhead costs.

**Table 1.2** Number of gangs required.

| Activity | Time required | Number of gangs |
|---|---|---|
| Plumbing carcass | 4 gang-days | 4 |
| Electrical carcass | 3 gang-days | 3 |
| Carpenter first fix | 2 gang-days | 2 |
| Plastering | 4 gang-days | 4 |
| Plumbing sanitary fittings | 3 gang-days | 3 |
| Electrical fittings | 1 gang-day | 1 |
| Carpenter second fix | 5 gang-days | 5 |

The work could be carried out using one gang in each unit (i.e. if two gangs are required, each gang would work on alternate units), or by using more than one gang in each unit, provided this does not result in overcrowding.

A line of balance schedule using one gang in each unit is shown in Fig. 1.8, which also shows the movement of some of the gangs. A 2 day buffer has been included to provide some flexibility.

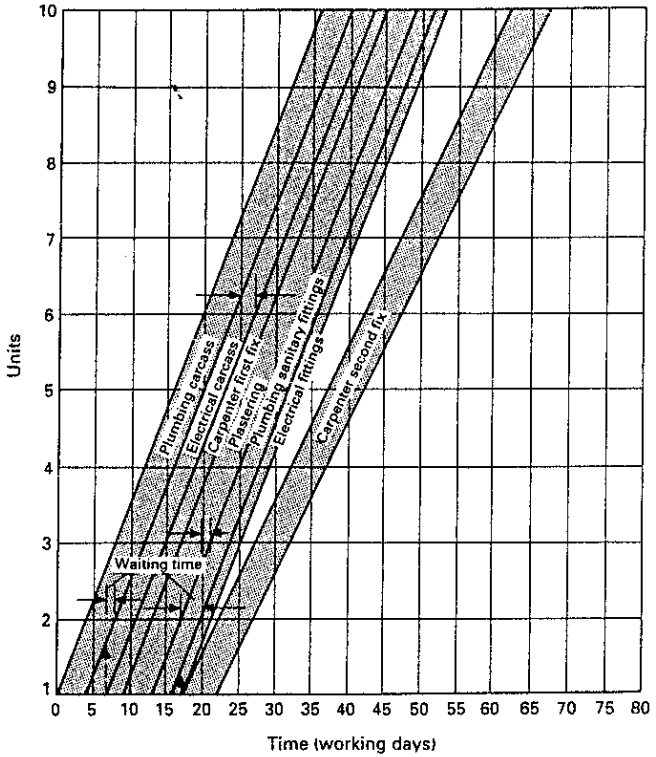



Fig. 1.7 Line of balance schedule: high direct costs.

### 1.6.2 *Introducing costs to the line of balance method*

The type of construction for repetitive projects can vary from traditional labour-intensive projects to system-built capital-intensive projects, and this will have an influence on the type of line of balance schedule used.

Basically line of balance schedules can be produced by one of two methods:

- *Method 1: Parallel scheduling.* In this method the lines of balance are drawn parallel to each other, progressing at the required rate of production, often with no buffer between them. To ensure that all activities should be able to progress at this rate, the number of gangs required is always rounded upwards. This method of scheduling would be used on capital-intensive projects, where site plant and site overheads are expensive. The cost of loss of production caused by overmanning is more than saved by the reduction in the overall planned duration of the project.
- *Method 2: Resource scheduling.* In this method the schedule is determined by the progress of each activity, and interference between activities is avoided at the planning stage. This results in a longer project duration and consequently greater project overheads. This method is used on labour-intensive projects. To reduce the project duration, some of the activities can be carried out in stages, using a different number of gangs in each stage.

The method of scheduling is determined mainly on economic grounds.



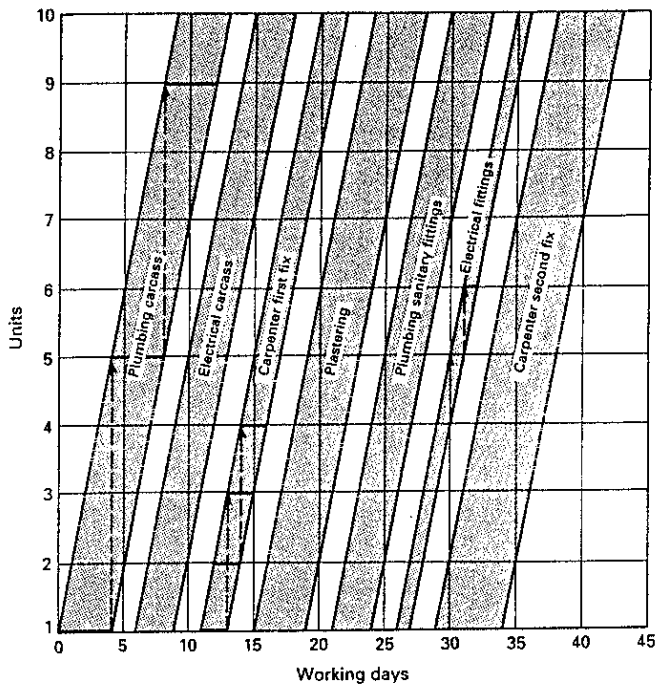



Fig. 1.8 Line of balance schedule: a better solution.

**Example 1.5: Refurbishment project**

Part of a refurbishment project consists of the erection of the shells for 100 extensions. The completion rate is to be 10 units per week and the working week is 5 days of 8 hours per day. All activities are to start at the beginning of a day, and a buffer of 2 days must be provided at all times.

The cost of labour is £72 per man per day, and site overheads are to be charged at £360 per day.

The activity data are shown in Table 1.3. As the construction consists of small extensions, no overlapping of activities will be allowed.

**Table 1.3** Activity data.

| Activity no. | Activity | Total man-hours per unit | Gang size |
|---|---|---|---|
| 1 | Demolition of existing lean-to and load rubble | 24 | 2 |
| 2 | Construct foundation and make drain connection | 16 | 2 |
| 3 | Brickwork to DPC level | 15 | 3 (2 + 1) |
| 4 | Oversite concrete and hardcore | 11 | 2 |
| 5 | Brickwork to roof level | 69 | 3 (2 + 1) |

***Method 1: parallel scheduling***

*Procedure for programming (Table 1.4)*

(1) Using the minimum optimum number of operatives, calculate the time required by this gang ($G$) (Col 4).

(2) The handover rate required is ten units per week. Based on a 40 hour week one unit must be handed over every 4 hours after completion of the first unit. Calculate the number of gangs required to give this handover rate, i.e. gang-hours/4. Round *up* the number of gangs to the nearest whole number. This is because of the high capital costs to ensure all operations proceed at a minimum of 10 units per week. This will balance the gangs as nearly as possible (Col 5).

(3) Calculate the number of units per week, i.e. $R = 40g/G$ (Col 6).

(4) Determine the number of gangs per unit, i.e. $P$ (Col 7).

(5) Calculate the duration required per unit, i.e. $T = G/8P$ (Col 8).



**Table 1.4** Parallel scheduling

| 1 Activity no. | Activity | 2 Total man hours per unit | 3 Min gang size | 4 Time reqd by min gang, $G$ | 5 Number of gangs, $g = G/t$ | 6 No. of units per week, $R = 40g/C$ | 7 No. of gangs per unit $P$ | 8 Time per unit (days), $T = G/8P$ | 9 Time from start first to start last (days), $5(N-1)/R$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Demolition | 24 | 2 | 12 | 3 | 10 | 1 | 1 5 | 49 5 |
| 2 | Foundations and drains | 16 | 2 | 8 | 2 | 10 | 1 | 1 | 49 5 |
| 3 | Brickwork to DPC | 15 | 3 (2 + 1) | 5 | 2 | 16 (10) | 1 | 0.625 | 30 94 (49 5) |
| 4 | Oversite concrete | 11 | 2 | $5\frac{1}{2}$ | 2 | 14 55 (10) | 1 | 0 7 | 34 02 (49 5) |
| 5 | Brickwork to roof | 69 | 3 (2 + 1) | 23 | 6 | 10 43 | 1 | 2 075 | 47 46 (49 5) |

**Table 1 5** Cost calculations for parallel scheduling

| | | |
|---|---|---|
| Demolition | 6 × £72 = £ 432 per day | Cost = 500/10 × £ 432 = £ 21 600 |
| Foundations | 4 × £72 = £ 288 per day | Cost = 500/10 × £ 288 = £ 14 400 |
| Brickwork to DPC | 6 × £72 = £ 432 per day | Cost = 500/10 × £ 432 = £ 21 600 |
| Oversite concrete | 4 × £72 = £ 288 per day | Cost = 500/10 × £ 288 = £ 14 400 |
| Brickwork to roof | 18 × £72 = £1296 per day | Cost = 500/10 × £1296 = £ 64 800 |
| | | £136 800 |
| | | Overheads 66 × 360 £ 23 760 |
| | | £160 560 |
| | Delay start of brickwork to roof | Cost = 500/10.43 × £1296 = £ 62 128 50 |
| | | Saving £ 2671 50 |

**Table 1 6** Additional calculations for resource scheduling with complete continuity for all activities.

| Activity no | Activity | Total man-hours per unit | Min. gang size | Time reqd by min. gang | Number of gangs | No. of units per week | No. of gangs per unit | Time per unit (days) | Time from start first to start last |
|---|---|---|---|---|---|---|---|---|---|
| 3 | Brickwork to DPC | 15 | 3 (2 + 1) | 5 | 1 | 8 | 1 | 0 625 | 61 88 |
| 4 | Oversite concrete | 11 | 2 | $5\frac{1}{2}$ | 1 | 7 27 | 1 | 0.7 | 68 09 |

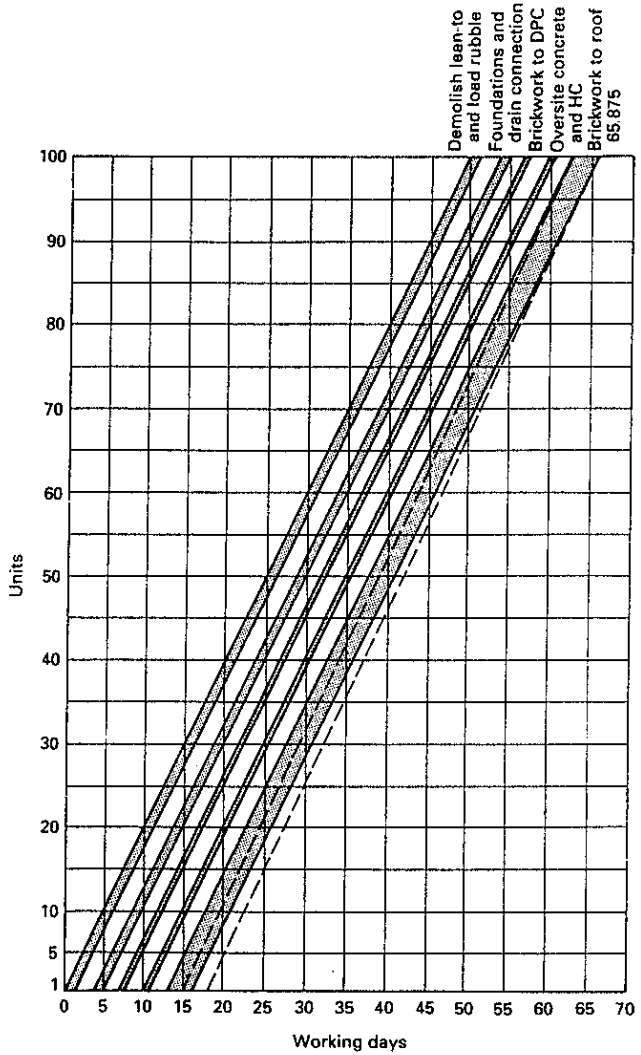



Fig. 1.9 Line of balance schedule: parallel scheduling.



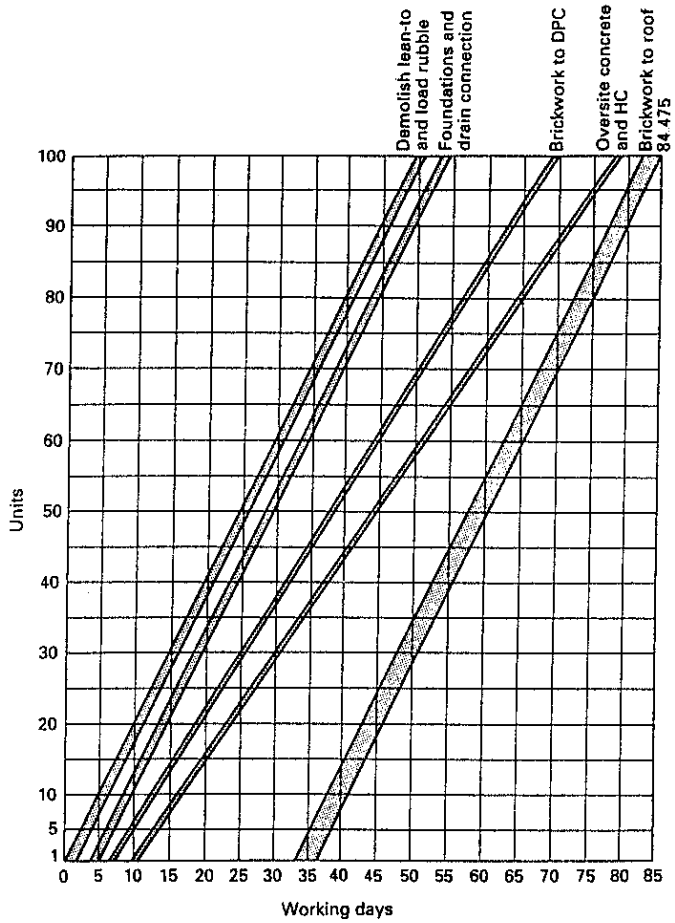



Fig. 1.10 Line of balance schedule: resource scheduling with complete continuity for all activities.

(6) Calculate the overall duration from the start of the first unit to the start of the last unit, i.e. $5(N-1)/R$, (Col 9) when $N$ is the number of units.

(7) Plot the line of balance schedule based on the above information (Fig. 1.9).

The line of balance schedule is shown in Fig. 1.9, and the cost calculations are shown in Table 1.5. The start time for brickwork to roof

could be delayed, and the activity could still be completed by day 66. This would result in a saving of £2671.50 as shown. This would not, however, be possible if the roof construction was to follow immediately after. The cost could of course be reduced by omitting the buffers, but in a project of this type this would result in considerable interference between gangs, which could outweigh any theoretical savings.

### *Method 2: resource scheduling*

*Resource scheduling with complete continuity for all activities*

The additional calculations are shown in Table 1.6, but the number of gangs is rounded to the nearest number. The line of balance schedule is shown in Fig. 1.10, and the cost calculations in Table 1.7. It can be seen that the project duration is extensive, owing to the different rates of progress of the activities, even though the gangs have been balanced as nearly as possible. If the gangs had been rounded upwards, the times from the start of the first unit to the start of the last one would have been as shown in Table 1.4 for each activity. The project duration would have been reduced by two days to 83 days, resulting in a saving of $2 \times £360 = £720$.

**Table 1.7** Cost calculations for resource scheduling.

| | | |
|---|---|---|
| Demolition | | 6 × £72 = £432 per day |
| Foundations | | 4 × £72 = £288 per day |
| Brickwork to DPC | | 3 × £72 = £216 per day |
| Oversite concrete | | 2 × £72 = £144 per day |
| Brickwork to roof | | 18 × £72 = £1296 per day |
| Cost = 500/10 | × £ 432 = £ | 21 600.00 |
| Cost = 500/10 | × £ 288 = £ | 14 400.00 |
| Cost = 500/8 | × £ 216 = £ | 13 500.00 |
| Cost = 500/7.27 | × £ 144 = £ | 9 904.50 |
| Cost = 500/10.43 | × £1296 = £ | 62 128.50 |
| | | £121 533.00 |
| Overheads 85 × £360 | | £ 30 600.00 |
| | | £152 133.00 |

*Resource scheduling with some activities carried out in stages*

A number of solutions are possible when adapting the schedule, and the optimum solution will depend on a number of factors, such as site overheads, cost of labour, the extent to which the activities are out of parallel, or the effects of lack of continuity. All the relevant factors must be taken into account when developing a solution, but because of all these factors determination of the optimum solution is extremely complex. In practical terms it is more appropriate to



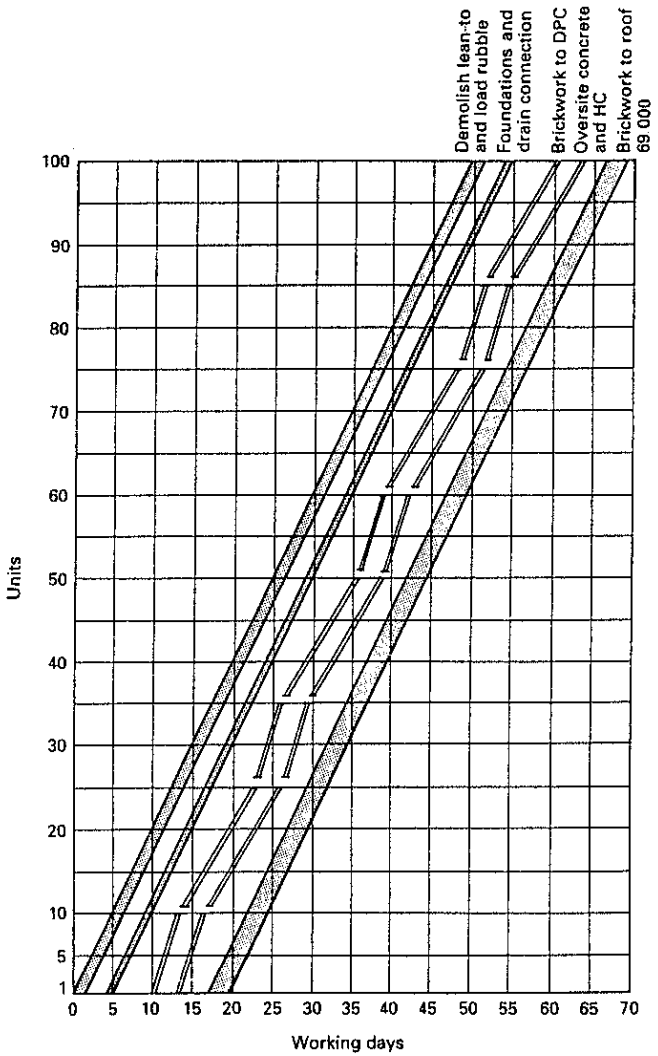



**Fig. 1.11** Line of balance schedule: resource scheduling with some activities carried out in stages.

analyse each schedule logically and determine an economic solution based on this approach.

To simulate the effects of non-continuity of work, a charge of £45 per man will be made each time resources are brought back to site. In this example one solution is to alternate the number of gangs on 'Brickwork to DPC' and on 'Oversite concrete'.

Considering the activity 'Brickwork to DPC', to achieve a 'start first' to 'start last' duration of 49.5 required for 10 units per week, it is necessary to alternate between two gangs and one gang. The number of units to be completed in each case can be calculated as follows:

activity duration in each unit using one gang = 0.625 days
average activity duration in each unit using two gangs = 0.3125 days

$$x \times 0.625 + (100 - x) \times 0.3125 = 50$$
$$0.625x - 0.3125x = 50 - 31.25 = 18.75$$
$$x = 18.75 - 0.3125$$
$$= 60 \text{ units}$$

Therefore 60 units are to be built using one gang and 40 units using two gangs.

As units are to be built in stages, build 15 units with one gang and 10 units with two gangs in each stage.

Additional calculations are necessary to determine the time from 'start first' to 'start last' in each stage as follows:

Fifteen units using one gang $5(15 - 1) \div 8 = 8.75$
Ten units using two gangs $5(10 - 1) \div 16 = 2.81$

Similar calculations for oversite concrete would not produce an economic programme, and it has therefore been decided to programme this activity in parallel with brickwork to DPC.

The line of balance schedule is shown in Fig. 1.11.

The adjustment to the price relative to the resource scheduling example shown in Fig. 1.10 is set out below:

| | | |
|---|---|---|
| *Saving in cost* | | |
| Overheads (85 – 69) × £360 | = £5760 | £5760 |
| *Additional costs* | | |
| Brickwork to DPC | | |
| 3 (men) × 3 (returns to site) × £45 | = £465 | |
| Oversite concrete | | |
| 2 × 3 × £45 | = £270 | |
| | £675 | £ 675 |
| | Savings = | £5085 |

# Reading

Shtub, A., Bard, J.F. and Globerson, S (1994) *Project Management. Engineering, Technology, and Implementation*, Prentice Hall International, Inc., pp. 374-397.

# 8

# Project Budget


8.1 Introduction
8.2 Project Budget and Organizational Goals
8.3 Preparing the Budget
8.4 Techniques for Managing the Budget
8.5 Presenting the Budget
8.6 Project Execution: Consuming the Budget
8.7 Important Points in the Budgeting Process


## 8.1 INTRODUCTION

An organization's budget (usually expressed in dollars) represents management's long-range, midrange, and short-range plans. The budget should contain a statement of prospective investments, management goals, resources necessary to achieve those goals, and a timetable. Its structure should match that of the organization. In particular, a functional structure shows an organization's investments and expenditures grouped three ways: (1) development of new products (engineering), (2) production of existing products (manufacturing), and (3) campaigns for new or existing products (advertising, marketing). A project-oriented structure, on the other hand, reveals the organization's planned costs and expected revenues for each project, while a matrix structure partially supports both the functional and project-based component of an organization's budget. This is explained presently.

The budget of any specific project is tied to the organizational budget. In some organizations, a project budget includes only expenditures (e.g., government agencies such as the Department of Defense are engaged in projects strictly as clients). In other organizations, the project budget includes both income and expenditures (e.g., contractors whose expenditures for labor, materials, and subcontracting are covered by their clients). When an organization is involved in several projects, the budgets of these projects are coordinated





centrally. It is important to combine the budget of each project to avoid the risk of steering the organization into financial difficulties. This issue should be considered when selecting new projects because it provides a hard constraint in the decision-making process.

In a matrix organization, the budget links the functional units to the projects. On a specific project the cost of resources invested by the functional unit is charged against the project's budget. This link is one of the interfaces between the functional structure and the project aspect of the matrix organization. In this chapter we discuss the principles used in developing, presenting, and using the budget in a project environment. The major focus is on the relationship between the organizational and the individual budgets of each project undertaken.

A well-designed budget is an efficient communication channel for management. Through the budget, managers (at all levels) are advised of their organizational goals and the resources allocated to their units. A detailed budget defines expected costs and expenditures, thus setting the framework of constraints within which each manager is expected to operate. These constraints represent organizational policy and goals. The well-structured budget is a yardstick that can be used to measure the performance of organizational units and their managers. Managers who participate in the budget development process commit themselves, their subordinates, and their unit's resources to the goals specified in the budget as well as the constraints implied by the negotiated funding levels. A successful manager is one who can achieve the budget goals with the resources allocated to his or her project, that is, one who can successfully execute the organization's policy. The well-structured budget is also a useful tool for identifying deviations from plans, the magnitude of these deviations, and their source. Therefore, it is part of the baseline for cost and schedule control systems. In addition, the budget's structure depends on the organizational structure, while its level of detail depends on the planning horizon for which it was prepared.

The *long-range*, or *strategic*, budget defines an aggregate level of activity for the organization over a period of several months to several years. For example, in a functional organization this budget might define a goal of selling 100,000 units in the coming year with a 15% increase in sales in each of the following 4 years. The expected marketing cost in the budget is $50,000 for the first year with 8% increases in each subsequent year. In an organization with a project structure, the strategic budget will define the total budget for each project. For example, assume that for project X the design stage has a 1-year completion due date and a $500,000 budget. A critical design review is scheduled accordingly. In 2 years a prototype will be tested in the lab. The associated budget is $600,000. The final product will be tested in the third year for a cost of $550,000. The long-range budget is typically updated annually.

By using the budgeting process, management establishes long-range goals, schedules to achieve these goals, and the available resources. When the actual expenditures, income and results are compared to the original budget, management can monitor the organization's performance. Also, when necessary, management can change the budget to control both goal setting and resource allocation.

A *midrange, tactical* budget is a detailed presentation of the long-range budget and covers 12 to 24 months. It is updated quarterly. The tasks to be performed provide the basis of the entries. A rolling planning horizon is used so that every time (e.g., quarterly) the

midrange budget is updated, a budget for the ensuing quarter is added while the budget for the recently completed quarter is deleted. The tactical budget details the monthly expected costs of labor, materials, and overhead for each task. In a functional organization, the tactical budget projects the expected costs and revenues of each product family and the expected costs of each functional department.

A *short-range* or *operational* budget lists specific activities and their costs. This budget spans a period up to 1 year and covers the costs of resources (such as labor and material) required to perform each activity. For example, the short-range budget of a project might specify that the design of a prototype be done on a $10,000 CAD system which runs on a $5,000 piece of equipment. Lead times are 3 and 2 weeks, respectively, for the hardware and software. Installation starts as soon as both items are delivered. The expected cost of installation and training is $2,000. This short-term (operational) budget relates project costs to project activities through the project's lower-level network model.

A project's budget contains several dimensions. The first relates to the tasks and activities to be performed. The primary effort is to establish the relationship between cost and time for scheduled tasks and activities. The second dimension is based on the organizational breakdown structure. Each task is assigned to an organizational unit in the OBS. The third dimension is the work breakdown structure. Each task is assigned to a WBS element in the lowest level of the hierarchy. Over time, however, they are distributed among the WBS elements at their corresponding levels.

As each organization develops its own budgeting procedures, several points can help make the budget an efficient vehicle for planning, as well as a standard channel of communication:

- The budget should present management's objectives stated in terms of measurable outputs: for example, the successful completion of a test or the development of a new software module. These outputs should be presented with their budgetary constraints. Thus the budget presents available resources and the goals to be achieved using these resources. The presentation can be based on a functional structure, a project's organizational structure, or a combination of the two if a matrix structure is assumed.
- The budget should be presented quantitatively (e.g., in monetary units or sometimes in person-hours) as a function of time. The presentation should facilitate a periodic and cumulative comparison between actual and planned performance levels.
- The budget should be divided into long-range (strategic), midrange (tactical), and short-range (operational) levels. Each level should contain a detailed breakdown of the budget at the preceding level for the planning horizon. A rolling horizon approach should be used in developing the budgets of new periods and in updating the budgets of previous periods.

Management reserve may be included at strategic and tactical levels. This reserve acts as a buffer against uncertainty and should be consumed by transforming it into specific line items in the mid- and short-range budgets.



## 8.2 PROJECT BUDGET AND ORGANIZATIONAL GOALS

The budget of an organization reflects management's goals. These goals and organizational constraints determine decisions on project selection, resource allocation, and the desired rate of progress for each project. The budget depends on the perceived organizational mission and the sector to which the organization belongs (private, government, or nonprofit). It also depends on internal and external environmental factors. The following are seven common factors affecting project selection and budget structure:

1. *Competition.* Most organizations in the private sector need a competitive edge to survive. External challenges force continued improvement within the organization and occur in various ways, such as the following:
   - *Time-based competition.* Spurs the implementation of concurrent engineering with the goal of shortening new product development cycles and improving customer service. It is also instrumental in reducing customer lead times. A major emphasis is on achieving project milestones and goals in a timely manner.
   - *Cost-based competition.* In a cost-based environment, the project budget includes smaller, tightly controlled reserves.
   - *Quality-based competition.* Total quality management is emphasized.

2. *Profit.* The ability to generate profits in the short and long run is essential to most organizations in the private sector. Selection decisions are frequently based on a project's expected profits. A project can be tentatively evaluated by any of the techniques discussed in Chapter 2, including net present value, internal rate of return, and payback period.

3. Cash flow. The organizational cash flow is an aggregate of all routine activities combined with other ongoing projects. When unexpected cash flow problems arise, projects that generate quick cash become high-priority items in the budget allocation process. In some cases an organization may prefer projects that begin to produce revenues immediately, albeit small, over projects that generate a slow cash flow and higher profits in the distant future. In the short run, to improve the cash position of the firm, activities that generate income (like payment milestones) may be budgeted earlier than other activities that have the same or an even shorter slack.

4. *Risk.* Uncertainty and risk may influence budgetary decisions. An organization that tries to avoid the risk of delays may budget its projects according to an early start schedule. This, in turn, may lead to early expenditures and cash flow problems. Organizations that try to minimize the risk of cost overruns sometime budget each activity at its lowest level. If a longer activity duration occurs, the lowered risk of a cost overrun can translate into an increased risk of delays.

The selection of new projects may also be influenced by risk assessment. In this case, the project's portfolio, to which the organization is committed, is affected by the organization's perceived risk level.

5. *Technological ability.* Some organizations in the public sector are willing to budget high-tech projects in order to acquire new, more advanced technologies. In the private sector (including such industries as computers, microelectronics, and aerospace), an organization's technological ability is an important aspect of its competitive edge. To outdistance competitors, technologically advanced projects are selected and budgeted to assure progress.

6. *Resources.* Each project's budget is a monetary representation of the value of resources allocated to perform that project. If adequate resources are not available, little can be accomplished, so whatever effort is expended will have negligible effect. Therefore, it is important to classify and track resources according to their availability. Chapter 9 presents a detailed classification scheme.

In the long- and midrange budgets, organizational plans for acquiring new resources are put forth. The short-range budget addresses plans to use these resources. In preparatory stages of a project, it is important to remember that some resources may not be available even if budgeted adequately. Therefore, in preparing the budget, resource availability (both inside and external to the organization) needs to be coordinated with the planned costs of these resources.

7. *Perceived Needs.* Project selection and budgeting depend largely on organizational goals. In the government sector, especially in defense, perceived needs (or new threats) are a driving force. Cost and risk considerations might be secondary when national security or public health are considered.

These seven factors link organizational goals and the internal and external aspects of the operational environment with each project's budget. Clearly, developing an organizational budget and a budget for each project requires a coordinated effort among management, accounting, marketing, and the other functional areas. This issue is the subject of the following section.

## 8.3 PREPARING THE BUDGET

Budget preparation is the process by which organizational goals are translated into a plan that specifies the allocated resources, the selected processes, and the desired schedule for achieving these goals. The budget must integrate information and objectives from all functional levels of the organization with information and objectives from the various project leaders. Although upper management sets the long-range (strategic) objectives, lower-level management is responsible for establishing the detailed (operational) plans and must clearly articulate and understand the short-range objectives before executing the budget.

In a project or a matrix organization, lower-level managers, who are concerned primarily with the daily operations, should be most knowledgeable in the technical details regarding the most appropriate way to perform each project. They should also be intimately



familiar with expected activity durations and costs. Thus it is important to integrate upper-level management input with the knowledge of the functional and project managers.

The organizational budget consists of both ongoing activities, such as the production and marketing of existing products, and one-time efforts or projects. It is easier to budget ongoing activities, since past budgets for these activities can serve as a reference point for planning. By adjusting for anticipated demand, the expected inflation rate, and the effect of learning, the financial planners can develop the new budget based on past information. Project budgeting is more difficult, though, since previous budgets are often unavailable. Cost estimation (Chapter 10), the project schedule (Chapter 7), and the effect of resource availability (Chapter 9) should be considered in developing the project budget.

The building blocks of the project's budget are the work packages in which tasks performed on the lowest-level WBS elements are assigned to organizational units at the lowest level of the OBS. A budget is developed for each work package. Budgets are then developed for each WBS element at each level in the hierarchy and for each organizational unit at each OBS level.

Thus the process of integrating single project budgets and the budgets of ongoing activities into an acceptable organizational budget requires planning and coordination. The final budget should embody sound, workable programs for each functional area, and coordinate the efforts of functional units and project managers to achieve their goals. Three procedures are commonly used in budgeting: the top-down approach, the bottom-up approach, and the iterative-mixed approach.

### 8.3.1 Top-Down Budgeting

The trigger for the budgeting process is the strategic long-range plan that is developed by top management based on its experience and perception of the organization's goals and constraints. The long-range plan is then passed to the functional unit managers and the project managers who develop the tactical (midrange) and detailed operational (short-range) budgets, respectively.

One problem with top-down budgeting is the translation of long-range budgets into short-range budgets. The former can be spread in any number of ways over the budgets of projects and functional units. The best combination yielding the most efficient schedule for each of the projects involved is not easy to construct given the constraints imposed by the long-range budget. Therefore, the question is how to schedule projects in a "suboptimal way" to meet the strategic goals. This suboptimality is a result of top management's limited knowledge of the specifics of each project, task, and activity, knowledge that is unavailable when preparing the long-range budget using the top-down approach.

A second problem with this approach is the competition for funds among lower-level managers who try to secure adequate funding for their operations. But since top management fixes the total budget, the only way for lower-level managers to gain an advantage is to undercut their counterparts. Such a situation does not promote cooperation and understanding and does not guarantee the optimal allocation of funds. Table 8-1 illustrates the top-down budgeting process.

TABLE 8-1 TOP-DOWN APPROACH TO BUDGET PREPARATION

| Step | Organizational level | Budget prepared at each step |
|---|---|---|
| 1 | Top management | Strategic budget based on organizational goals, constraints, and policies |
| 2 | Functional management | Tactical budget for each functional unit |
| 3 | Project managers | Detailed budgets for each project, including the cost of labor, material, subcontracting, overhead, etc. |

### 8.3.2 Bottom-Up Budgeting

To overcome the disaggregation problem of top-down budgeting, many organizations adopt a budgeting approach starting at the project manager level. Each project manager is asked to prepare a budget proposal that supports efficient and on-schedule project execution. Based on these proposals, functional managers prepare the budgets for their units, considering the resources required in each period. Finally, top management streamlines and integrates the individual project and functional unit budgets into a strategic long-range organizational budget.

The advantages of this approach are the clear flow of information and the use of detailed data available at the project management level as the basic source of cost, schedule, and resource requirement information. The disadvantage of the approach is that top management has limited influence over the budgeting process, since the functional and project managers prepare most of the short- and midrange budgets. However, top management can influence the outcome by issuing a statement to the lower-level managers, as they prepare the short- and mid-range budgets, outlining organizational policies and goals. Also, top management can steer the budgeting process by selecting projects based on its perception of organizational needs and goals. Table 8-2 illustrates the bottom-up budgeting process.

As stated, the major problem with the bottom-up approach is the reduced level of control it offers top management. Since the aggregate budget is developed based on input obtained from the project and functional unit managers, the gap between strategic and operational objectives may be wide. This creates a need to fine tune the organizational budget. The process is carried out iteratively through adjustment and review until a satisfactory compromise is achieved.

TABLE 8-2 BOTTOM-UP APPROACH TO BUDGET PREPARATION

| Step | Organizational level | Budget prepared at each step |
|---|---|---|
| 1 | Top management | Setting goals and selection of projects (a framework for budget) |
| 2 | Project management | Detailed budget proposals for projects including costs of material, labor, subcontracting, etc. |
| 3 | Functional management | Midrange budget for each functional unit |
| 4 | Top management | Adjustments and approval of the aggregate long plan budget resulting from the process |



### 8.3.3 Iterative Budgeting

The two budgeting approaches presented above are "pure" in that the process flows in one direction, either bottom-up or top-down. Some of the shortcomings of these approaches can be eliminated by combining the information flows in an iterative fashion. A typical iterative approach starts with top management setting a budget framework for each year of a strategic plan. This framework then directs the selection of new projects and serves as a guideline for project managers as they prepare their budgets. Detailed project budgets are aggregated into functional unit budgets and finally, into an organizational budget that top management reviews and, if necessary, modifies. Based on the approved budget, functional unit and project managers modify their respective budgets. The process may undergo several iterations until convergence takes place at the strategic, tactical, and operational levels.

This process is based on input from all levels of management and usually produces better coordination between the different budgets (functional versus project and long-range versus short- and midrange). Major disadvantages center on the relatively long duration needed for agreement and the excessive use of management time.

The process of adjusting a project budget to the framework of the organizational budget is based on the internal relationship between schedule, resources, and cost. This relationship can be exploited in several ways, as explained next.

## 8.4 TECHNIQUES FOR MANAGING THE BUDGET

The budget of a project represents scheduled expenditures and scheduled revenue as a function of time. The simplest approach to budgeting is to estimate the expected costs and income associated with each activity, task, and milestone. Based on the project schedule, these costs are assigned specific dates and a budget is generated; however, it may be only a partial budget because some of the indirect costs are usually not included at the preliminary stage. Typical indirect costs are those for management, facilities, and quality control and are not always related to specific activities. Adding these costs results in a more complete project budget. The product of this effort can serve as the basis for the decision-making process needed to develop a detailed, comprehensive budget. The development of detailed project budgets based on schedule and resource considerations is the first step in an iterative approach. The next step is to integrate them into an acceptable organizational budget.

### 8.4.1 Slack Management

One approach to integrating these projects is to change activity timing and the associated expenditure or income, an approach known as slack management. Noncritical activities that have free slack are usually the first candidates for this type of rescheduling. Activities with total slack are the next choices, and the final choices are critical activities that can be delayed only at the cost of delays in project completion time. Rescheduling activities makes the integration of single project budgets into an acceptable organizational budget easier.

To illustrate the relationship between a project's cash flow and its schedule, let us return to the example project. The length of the critical path in the project is 22 weeks. Critical activities are A, C, F, and G, while activities B, E, and D have either free or total slack that can be used for budget planning. Table 8-3 depicts the costs and durations of the project's activities.

An early start schedule results in relatively high expenditures in the project's earlier stages, while a late start schedule results in relatively high expenditures in the later stages. Table 8-4 presents this project's cash flow for the early start schedule assuming, for budgeting purposes, that the cost of each activity is evenly distributed throughout its duration. Table 8-5 enumerates the cash flow of the project for the late start case.

Figure 8-1 depicts the cash flows for the early and late start schedules; Fig. 8-2 depicts their cumulative cash flows. From Fig. 8-2 we see that if the strategic long-range organizational budget allocates only $4,913 to the project for weeks 1 through 5, then during this period only a late start schedule is feasible. Also, increasing the project's budget over $10,398 for the first 5 weeks makes an early start schedule feasible. Any budget in-between will force a delay of noncritical activities.

The choice between an early and a late start schedule affects the risk level associated with the project's on-time completion. Using a late start schedule means that all the activities are started as late as possible without any slack to buffer against uncertainty, increasing the probability of delays. Therefore, the budgeting process should resolve the conflict between a project budget that supports the organizational budgeting requirements versus the higher risk of a schedule overrun.

Projects with large numbers of activities tend to have a large choice of schedules with associated budgets. For example, in Fig. 8-1, any schedule that falls between the early and late start budget lines would be feasible from the point of view of meeting the critical milestones on time.

### 8.4.2 Crashing

In addition to using slack management as part of the budgeting process, another option may be available: change activity duration by selecting different technologies to perform the

**TABLE 8-3** PROJECT ACTIVITY DURATIONS AND COSTS

| Activity | Duration (weeks) | Cost ($1,000) |
|---|---|---|
| A | 5 | 1.5 |
| B | 3 | 3.0 |
| C | 8 | 3.3 |
| D | 7 | 4.2 |
| E | 7 | 5.7 |
| F | 4 | 6.1 |
| G | 5 | 7.2 |
| | | 31.0 |



**TABLE 8-4** CASH FLOW OF AN EARLY START SCHEDULE

| | Activity | | | | | | | Weekly | Cumulative |
|---|---|---|---|---|---|---|---|---|---|
| Week | A | B | C | D | E | F | G | cost | cost |
| 1 | 300 | 1,000 | | | 814.3 | | | 2,114 | 2,114 |
| 2 | 300 | 1,000 | | | 814.3 | | | 2,114 | 4,229 |
| 3 | 300 | 1,000 | | | 814.3 | | | 2,114 | 6,343 |
| 4 | 300 | | | | 814.3 | | | 1,114 | 7,457 |
| 5 | 300 | | | | 814.3 | | | 1,114 | 8,571 |
| 6 | | | 412.5 | 600 | 814.3 | | | 1,827 | 10,398 |
| 7 | | | 412.5 | 600 | 814.3 | | | 827 | 12,225 |
| 8 | | | 412.5 | 600 | | | | 1,013 | 13,238 |
| 9 | | | 412.5 | 600 | | | | 1,013 | 14,250 |
| 10 | | | 412.5 | 600 | | | | 1,013 | 15,263 |
| 11 | | | 412.5 | 600 | | | | 1,013 | 16,275 |
| 12 | | | 412.5 | 600 | | | | 1,013 | 17,288 |
| 13 | | | 412.5 | | | | | 412 | 17,700 |
| 14 | | | | | | 1,525 | | 1,525 | 19,225 |
| 15 | | | | | | 1,525 | | 1,525 | 20,750 |
| 16 | | | | | | 1,525 | | 1,525 | 22,275 |
| 17 | | | | | | 1,525 | | 1,525 | 23,800 |
| 18 | | | | | | | 1,440 | 1,440 | 25,240 |
| 19 | | | | | | | 1,440 | 1,440 | 26,680 |
| 20 | | | | | | | 1,440 | 1,440 | 28,120 |
| 21 | | | | | | | 1,440 | 1,440 | 29,560 |
| 22 | | | | | | | 1,440 | 1,440 | 31,000 |
| | 1,500 | 3,000 | 3,300 | 4,200 | 5,700 | 6,100 | 7,200 | 31,000 | |

activity and by adding or deleting the necessary resources. So far we have assumed that each activity is performed in the most economical way. Thus the combination of resources assigned to each activity is assumed to be selected to minimize the total cost of performing that activity. However, in many cases it is possible to reduce an activity's duration by spending more money. Thus trade-offs exist between the minimum cost–longest duration option at one extreme and any other option that reduces an activity's duration at a higher cost.

This is the essence of the original version of CPM, which places equal emphasis on time and cost. The emphasis is achieved by constructing a time–cost curve for each activity, such as the one shown in Fig. 8-3. This curve plots the relationship between the direct cost for the activity and its resulting duration. In its simplest form, the plot is typically based on two points: the *normal* point and the *crash* point. The former gives the cost and time involved when the activity is performed in the normal way without extra resources such as overtime, special materials, or improved equipment that could speed things up. By contrast, the crash point gives the time and cost when the activity is fully expedited; that is, no cost is spared to reduce its duration as much as possible. As an approximation, it is then assumed that all intermediate time–cost trade-offs are possible and that they lie on the line segment between these two points (see the line segment in Fig. 8-3). Thus the only estimates needed are the cost and time for normal and crash points.

**TABLE 8-5** CASH FLOW OF THE LATE START SCHEDULE

| Week | Activity A | B | C | D | E | F | G | Weekly cost | Cumulative cost |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 300 | | | | | | | 300 | 300 |
| 2 | 300 | | | | | | | 300 | 600 |
| 3 | 300 | 1,000 | | | | | | 1,300 | 1,900 |
| 4 | 300 | 1,000 | | | | | | 1,300 | 3,200 |
| 5 | 300 | 1,000 | | | | | | 1,300 | 4,500 |
| 6 | | | 412.5 | | | | | 412 | 4,913 |
| 7 | | | 412.5 | 600 | 814.3 | | | 1,827 | 6,739 |
| 8 | | | 412.5 | 600 | 814.3 | | | 1,827 | 8,566 |
| 9 | | | 412.5 | 600 | 814.3 | | | 1,827 | 10,393 |
| 10 | | | 412.5 | 600 | 814.3 | | | 1,827 | 12,220 |
| 11 | | | 412.5 | 600 | 814.3 | | | 1,827 | 14,046 |
| 12 | | | 412.5 | 600 | 814.3 | | | 1,827 | 15,873 |
| 13 | | | 412.5 | 600 | 814.3 | | | 1,827 | 17,700 |
| 14 | | | | | | 1,525 | | 1,525 | 19,225 |
| 15 | | | | | | 1,525 | | 1,525 | 20,750 |
| 16 | | | | | | 1,525 | | 1,525 | 22,275 |
| 17 | | | | | | 1,525 | | 1,525 | 23,800 |
| 18 | | | | | | | 1,440 | 1,440 | 25,240 |
| 19 | | | | | | | 1,440 | 1,440 | 26,680 |
| 20 | | | | | | | 1,440 | 1,440 | 28,120 |
| 21 | | | | | | | 1,440 | 1,440 | 29,560 |
| 22 | | | | | | | 1,440 | 1,440 | 31,000 |
| | 1,500 | 3,000 | 3,300 | 4,200 | 5,700 | 6,100 | 7,200 | 31,000 | |

Consider, for example, a manual painting operation requiring 4 days at $400 per day. With a special compressed airflow system, however, two workers can complete the job in 2 days for $1,000 per day. Thus the activity can be performed in 4 days for $400 × 4 = $1,600 or in 2 days for $1,000 × 2 = $2,000. The normal duration is associated with the lowest-cost option for the activity. This value is used in a CPM analysis and in the preparation of the initial budget.

More formally, the normal duration of an activity is the duration that minimizes the direct cost. In some instances a schedule based on normal durations may produce high indirect costs, for example, when a project due date is given and a penalty is charged for completion after the due date. Even when the due date can initially be met by a normal schedule, uncertainty during the project execution may cause schedule overruns. The resultant penalties must be traded off with the cost of shortening the duration of some activities to minimize (or avoid completely) these late charges.

A similar situation occurs when a fixed overhead is charged for a project's duration. Rent for facilities would be such an example. In this case, management might consider shortening some activities to reduce the project's duration and hence save on indirect costs.

*Crashing* is the procedure whereby an activity's duration is shortened by adding resources and paying extra direct costs. A crashed program includes activities performed more

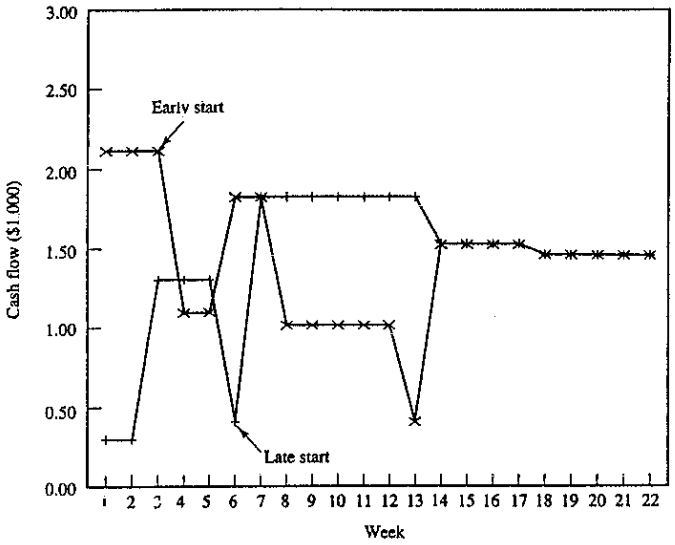



**Figure 8-1** Cash flow for early start and late start schedules.

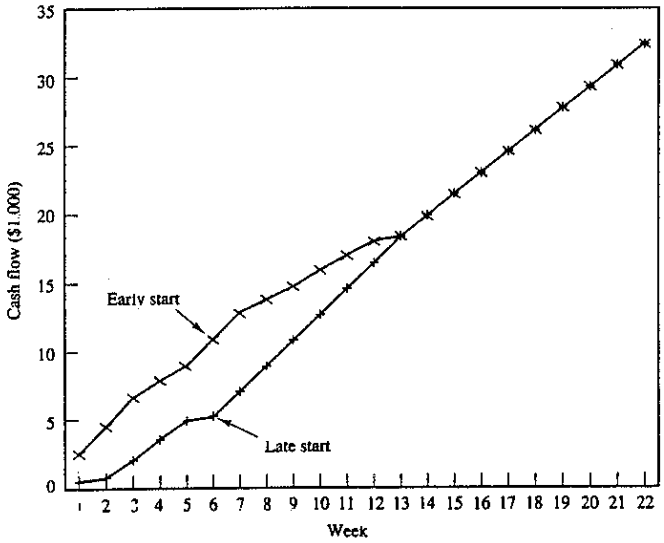



**Figure 8-2** Cumulative cash flow for early start and late start schedules.

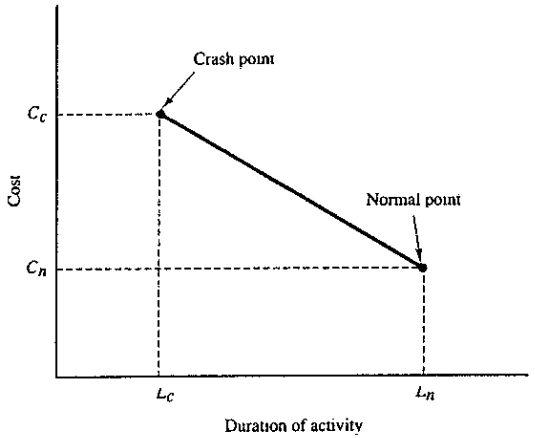



**Figure 8-3** Typical time–cost trade-off curve.

quickly than they normally would be due to the allocation of additional resources. To plan a crashed program, management must decide which activities to crash and by how much. To illustrate this point, consider the crashing costs and durations list in Table 8-6 for the example project.

In Table 8-6, the normal duration and the normal cost of each activity are those used in the basic schedule. Each activity can be crashed at least once. Five of the activities (A,C,D,F,G) can be crashed twice, as the table shows.

It is possible to construct the relationship between the project's duration and its direct cost, starting with an all normal schedule where each activity is performed at its lowest direct cost and at a normal duration. To reduce the project's length, the critical path must be shortened. Thus, at each step, the critical path(s) are examined, and the activity that is least expensive to crash is selected for crashing on each critical path. These activities are crashed, and the process continues with the new critical paths being examined. In case the activities are not crashed in the same amount of time, it is possible to use the cost of crashing per period as a measure of attractiveness to select activities to crash.

To illustrate this heuristic process, consider the data in Table 8-6. The project's normal duration is 22 weeks, and the critical activities are A, C, F, and G. Reducing the project's length requires crashing one critical activity. At this stage, the cost of crashing each critical activity is as follows:

| Activity | Cost to crash |
|---|---|
| A | $2,000 |
| C | 2,000 |
| F | 1,000 |
| G | 1,000 |



**TABLE 8-6** DURATION AND COST FOR NORMAL AND CRASHED ACTIVITIES

| | Normal | | Crashing activity the first time | | Crashing activity a second time | |
|---|---|---|---|---|---|---|
| Activity | Cost | Duration (weeks) | Additional cost | Duration (weeks) | Additional cost | Duration (weeks) |
| A | $1,500 | 5 | $2,000 | 4 | $1,000 | 3 |
| B | 3,000 | 3 | 2,000 | 2 | — | — |
| C | 3,300 | 8 | 2,000 | 7 | 1,000 | 6 |
| D | 4,200 | 7 | 2,000 | 6 | 2,000 | 5 |
| E | 5,700 | 7 | 1,000 | 6 | — | — |
| F | 6,100 | 4 | 1,000 | 3 | 2,000 | 2 |
| G | 7,200 | 5 | 1,000 | 4 | 1,000 | 3 |

Activities F and G are the least expensive to crash. In particular, the cost of activity F crashed from 4 to 3 weeks is $7,100, as illustrated in Table 8-7. The first column in the table represents the project with a normal duration (22 weeks). The second column represents the project after crashing F from 4 to 3 weeks; the project's duration is now 21 weeks and the crashed activity (F) is marked by an asterisk (*). The crashing procedure can continue until a 14-week span is obtained. At this point, two critical paths emerge: A–C–F–G, which lasts 14 weeks and contains no activities that can be crashed further; and B–D–F–G, which also lasts 14 weeks but contains two activities, B and D, which can be crashed for $2,000 and $3,000, respectively. Since the length of sequence A–C–F–G cannot be reduced, the project's minimum duration is 14 weeks. Table 8-7 summarizes the results.

Budgeting decisions are easier when the time–cost relationship for a project is known. The following example analyzes the trade-off between direct and indirect costs. Suppose that a fixed overhead of $500 per week is charged for a project's duration. Further, assume that the project is due in 18 weeks and that a penalty of $1,000 per week is imposed starting the nineteenth week. The budget problem in this case translates into a trade-off between the cost of crashing and the overhead plus penalty. Table 8-8 summarizes these cost components, accompanied by the project's total costs as a function of its length.

Based on Table 8-8, the minimum cost occurs at a project length of 19 weeks; that is, it is more economical to pay a penalty of $1,000 and an overhead of $500 for the nineteenth week than to crash activity F for $2,000. The total project cost may not be the only criterion for budget planning. If, for example, customer satisfaction depends on project completion within 18 weeks, the $500 savings should be evaluated against the customer goodwill that might be lost. Budgeting decisions should be based on this evaluation.

Figure 8-4 graphically depicts the different cost components and the total cost of the project as a function of its duration. The crashing problem can be modeled as either a linear or mixed-integer linear program, depending on whether a continuous trade-off exists between an activity's duration and cost (as assumed in Fig. 8-3), or whether only certain combinations are possible. The formulation presented below reflects the latter case, where

**TABLE 8-8** PROJECT COSTS AS A FUNCTION OF ITS DURATION

| Project length (weeks) | Direct cost of activities | Late completion penalty | Overhead cost | Total project cost |
|---|---|---|---|---|
| 22 | $31,000 | $4,000 | $11,000 | $46,000 |
| 21 | 32,000 | 3,000 | 10,000 | 45,500 |
| 20 | 33,000 | 2,000 | 10,500 | 45,000 |
| 19 | 34,000 | 1,000 | 9,500 | 44,500 |
| 18 | 36,000 | 0 | 9,000 | 45,000 |
| 17 | 38,000 | 0 | 8,500 | 46,500 |
| 16 | 39,000 | 0 | 8,000 | 47,000 |
| 15 | 41,000 | 0 | 7,500 | 48,500 |
| 14 | 44,000 | 0 | 7,000 | 51,000 |




**Figure 8-4** Example project cost as a function of its duration.

only a finite number of time–cost combinations are available for each activity. Assuming an activities-on-arrow network, the following notation is used:

$i$ = index for events on the AOA network model; $i \in N = \{1,\ldots,n\}$, where $i = 1$ is the unique "start" event that has no predecessors and $i = n$ is the unique "end" event that has no successors

$(i,j)$ = project activity that starts at event $i$ and ends at event $j$; $(i,j) \in A$

$k$ = index for a particular time–cost combination

$K(ij)$ = index set of possible time–cost combinations for activity $(i,j)$

$L_{ijk}$ = duration of activity $(i,j)$ when it is performed at time–cost combination $k$

$C_{ijk}$ = direct cost of activity $(i,j)$ if performed at time–cost combination $k$

$C_o$ = overhead cost per period of time



**TABLE 8-7** CRASHING THE PROJECT (COST IN $1,000, DURATION IN WEEKS)

| Activity | 22 Weeks | | 21 Weeks | | 20 Weeks | | 19 Weeks | | 18 Weeks | | 17 Weeks | | 16 Weeks | | 15 Weeks | | 14 Weeks | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cost | Dur. | Cost | Dur. | Cost | Dur. | Cost | Dur | Cost | Dur. | Cost | Dur. | Cost | Dur. | Cost | Dur. | Cost | Dur. |
| A | 15 | 5 | 15 | 5 | 15 | 5 | 15 | 5 | 15 | 5 | 35* | 4 | 45* | 3 | 45 | 3 | 45 | 3 |
| B | 30 | 3 | 30 | 3 | 30 | 3 | 30 | 3 | 30 | 3 | 30 | 3 | 30 | 3 | 30 | 3 | 30 | 3 |
| C | 33 | 8 | 33 | 8 | 33 | 8 | 33 | 8 | 33 | 8 | 33 | 8 | 33 | 8 | 53* | 7 | 63 | 6 |
| D | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 62* | 6 |
| E | 57 | 7 | 57 | 7 | 57 | 7 | 57 | 7 | 57 | 7 | 57 | 7 | 57 | 7 | 57 | 7 | 57 | 7 |
| F | 61 | 4 | 71* | 3 | 71 | 3 | 71 | 3 | 91* | 2 | 91 | 2 | 91 | 2 | 91 | 2 | 91 | 2 |
| G | 72 | 5 | 72 | 5 | 82* | 4 | 92* | 3 | 92 | 3 | 92 | 3 | 92 | 3 | 92 | 3 | 92 | 3 |
| Total cost of activities | 31 | | 32 | | 33 | | 34 | | 36 | | 38 | | 39 | | 41 | | 44 | |

*Crashed activity.

*Decision variables*

$t_i$ = time event $i$ takes place

$y_{ijk}$ = (binary) equal to 1 if time–cost combination $k \in K(ij)$ is selected for activity $(i,j)$; 0 otherwise

The problem of minimizing total cost is

$$\min\left[C_o t_n + \sum_{(i,j)\in A} \sum_{k\in K(ij)} C_{ijk} y_{ijk}\right] \tag{8-1a}$$

subject to

$$t_j - t_i \geq \sum_{k\in K(ij)} L_{ijk} y_{ijk} \qquad \text{for all } (i,j) \in A \tag{8-1b}$$

$$\sum_{k\in K(ij)} Y_{ijk} = 1 \qquad \text{for all } (i,j) \in A \tag{8-1c}$$

$$t_1 = 0, \quad t_i \geq 0, \qquad y_{ijk} = 0 \text{ or } 1 \tag{8-1d}$$

The objective function (8-1a) represents the project's total cost, which is composed of a direct and an indirect component. The first set of constraints (8-1b) maintains the precedence relations in the network; the second set (8-1c) ensures that each activity is performed at one of its time–cost combinations.

As an example of the model, consider the following project:

| Activity (start event, end event) | Time–cost combination 1 | | Time–cost combination 2 | |
|---|---|---|---|---|
| | Time (weeks) | Cost | Time (weeks) | Cost |
| (1,2) | 5 | $100 | 3 | $150 |
| (1,3) | 4 | 70 | 3 | 100 |
| (2,4) | 4 | 200 | 3 | 300 |
| (3,4) | 6 | 500 | 3 | 900 |

The effect of the overhead cost per period ($C_o$) on the optimal schedule can be analyzed by solving (8-1) for the example and varying the value of $C_o$. The specific model for this example follows:

$$\min C_o i_4 + 100y_{121} + 150y_{122} + 70y_{131} + 100y_{132} + 200y_{241} + 300y_{242} + 500y_{341} + 900y_{342}$$

subject to



$$t_2 - t_1 \geq 5y_{121} + 3y_{122}$$
$$t_3 - t_1 \geq 4y_{131} + 3y_{132}$$
$$t_4 - t_2 \geq 4y_{241} + 3y_{242}$$
$$t_4 - t_3 \geq 6y_{341} + 3y_{342}$$

$$y_{121} + y_{122} = 1$$
$$y_{131} + y_{132} = 1$$
$$y_{241} + y_{242} = 1$$
$$y_{341} + y_{342} = 1$$

$$t_1 = 0, \quad t_i \geq 0, \quad i = 2,\ldots,4;$$
$$y_{ijk} = 0 \text{ or } 1 \text{ for } (i,j) \in A = \{(1,2),(1,3),(2,4),(3,4)\}, \quad k = 1,2$$

Solving the model for different values of the overhead cost, $C_o$, gives the solutions presented in Table 8-9. The trade-off between the overhead cost and the cost of crashing activities is clear from these results. It is not justified to crash any activity whose overhead cost is below $20 per period. The first activity to be crashed is (1,3) and it is the only one for a wide range of $C_o$ values. Only when the overhead per period is between $180 and $190 is it justified to crash all four activities.

**TABLE 8-9** PARAMETRIC SOLUTION TO TIME–COST TRADE-OFF EXAMPLE (COST IN DOLLARS, DURATION IN WEEKS)

| Overhead Cost $C_o$ | Activity (1,2) | | Activity (1,3) | | Activity (2,4) | | Activity (3,4) | | Project | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cost | Duration | Cost | Duration | Cost | Duration | Cost | Duration | Cost | Duration |
| 10 | 100 | 5 | 70 | 4 | 200 | 4 | 500 | 6 | 970 | 10 |
| 20 | 100 | 5 | 70 | 4 | 200 | 4 | 500 | 6 | 1,070 | 10 |
| 30 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 1,170 | 9 |
| 40 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 1,260 | 9 |
| 50 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 1,350 | 9 |
| 60 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 1,440 | 9 |
| 70 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 1,530 | 9 |
| 80 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 1,620 | 9 |
| 90 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 1,710 | 9 |
| 100 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 1,800 | 9 |
| 110 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 1,890 | 9 |
| 120 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 1,980 | 9 |
| 130 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 2,070 | 9 |
| 140 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 2,160 | 9 |
| 150 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 2,250 | 9 |
| 160 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 2,340 | 9 |
| 170 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 2,430 | 9 |
| 180 | 100 | 5 | 100 | 3 | 200 | 4 | 500 | 6 | 2,520 | 9 |
| 190 | 150 | 3 | 100 | 3 | 300 | 3 | 900 | 3 | 2,590 | 6 |
| 200 | 150 | 3 | 100 | 3 | 300 | 3 | 900 | 3 | 2,650 | 6 |

Budgeting decisions are influenced by external factors such as the cost of money. If this cost is high, the net present value of the project may become an important criterion in budgeting. The reference list at the end of the chapter contains several papers dealing with this subject. The intuitive approach to project budgeting under the NPV criterion is to delay activities that require a capital outlay and to start, as early as possible, activities that generate cash. Since most activities lead to customer payment (i.e., cash generation) but require a capital outlay, a trade-off analysis is required to schedule these activities in the best possible way from the perspective of the budget.

### 8.4.3 PERT/Cost

PERT/Cost is a cost accounting technique for achieving realistic estimates of costs associated with activities and for providing an information system that allows good control of interim project costs. The federal government, which originally published the technique, uses it regularly for controlling cost overruns in governmental contracts. The need for an accounting system that is conceptually consistent with project management becomes evident when one considers that traditional systems group costs not by activities but by organizational areas, flows of materials, and time periods. PERT/Cost provides a means for structuring costs that is consistent with project management models.

With respect to planning and scheduling, PERT/Cost generates cumulative and average expenditures on a period-by-period basis for alternative schedules. This feature is useful in deciding when activities should be started between their earliest and latest starting dates. Additionally, the information system for PERT/Cost provides reports that allow project managers to control costs and evaluate performance with respect to the schedule. For example, suppose that at some point in time actual cost for an activity is 80% of budgeted cost at some point in time. One might think that cost is under control; however, the activity may be only 50% complete. To overcome this problem, a set of criteria called *cost/schedule control systems criteria* were developed, which we discuss in Chapter 11.

## 8.5 PRESENTING THE BUDGET

The project budget is a communications channel that must serve both internal and organizational planning and control needs. Two dimensions are used to measure the quality of a project's budget: the budget's ability (1) to advance organizational goals within the imposed constraints, and (2) to communicate the proposed plan to the project team and organization, and sometimes to subcontractors and the client.

The budget is easier to understand and use if it is presented clearly and concisely. Consider the following recommendations when preparing and presenting a project's budget:

**1.** Incorporate a schedule indicating the time that expenditures and revenues are expected to be realized.

**2.** Present the budget in quantitative, measurable units such as dollars or person-hours. If you use different units in the same budget, clearly define the conversion between units.



**3.** Make an effort to define milestones corresponding to the achievement of measurable goals. Typical milestones for R&D projects are system design review, preliminary design review, critical design review, and the passing of prototype performance tests. In contractor–client projects, the achievement of such milestones can serve as the basis for client payments. It is important to budget milestones according to the costs of activities leading up to them. In the example project (see Fig. 7-22), if event 3 is defined as a milestone representing the completion of activities A and B, its budget is based on the costs of activities A and B ($4,500). Assuming an early start schedule, these activities are scheduled to terminate 5 weeks after the project initiation. Assuming a $2,500 overhead (or $500 per week), the total payment of this milestone is likely to be above $4,500 and close to $7,000.

**4.** Use the budget as a baseline for progress monitoring and control. If a weekly progress report is required, plan the budget at the weekly level. On the other hand, if weekly progress reports are issued but the budget is prepared on a monthly basis, a meaningful comparison between planned progress and actual progress is possible only once every four progress reports. Similarly, break down the budget to enable a direct comparison with the progress reports. The cost breakdown used in preparing the budget should be the same as the breakdown used to collect and analyze data for both the project and organizational control systems.

**5.** The budget should translate short-range objectives into work orders, purchasing orders, and so on. This links the design and development phases to the production phase through the budgeting and work authorization processes.

**6.** Break down the budget by the organizational units responsible for its execution and the work content assigned to such units. For example, Table 8-10 itemizes the activities by assigned departments of the example project.

**7.** Whenever you use a specific standard in budgeting, reference it. For example, suppose that activity C is welding the pressure tank of a submarine and is budgeted at $3,300. This figure might have been derived from the company standard, which says that it costs $300 per inch to perform a weld. The estimated welding length is 11 inches. Such information should be referenced in the budget. By referencing the standard used, you can later trace any deviations in actual cost to the deviation's source (i.e., the cost per inch or the length of the welding) and, if necessary, update the standard.

**TABLE 8-10** BREAKDOWN OF THE BUDGET BY ORGANIZATIONAL UNITS

| Activity | Department 1 | Department 2 |
|---|---|---|
| A | | $1,500 |
| B | | 3,000 |
| C | $3,300 | |
| D | 4,200 | |
| E | | 5,700 |
| F | 6,100 | |
| G | 7,200 | |
| Department total | $20,800 | $10,200 |

8. Include five components in the short-term (operational) budget:
   (a) *Work packages of discrete effort.* Each work package defines the organizational element responsible for a task and the task's WBS element. Identifying the work package this way allows you to present the budget along WBS and OBS lines. Such an identification also serves as a baseline for a control system capable of tracing the sources of deviations between planned and actual progress, as explained in Chapter 11.
   (b) *Level of effort.* This category, which includes the cost of efforts related to more than one work package, occurs as the activities progress over time.
   (c) *Apportioned effort.* This category includes the cost of efforts based on a factor of a discrete effort (work package) as exemplified by such activities as inspection and quality control.
   (d) *Cost of material.* These costs include the WBS element for which it will be used and the OBS element that will use it.
   (e) *Other costs.* Costs such as those associated with subcontracting must be included.

9. Budget planners should try to define most of the project's effort in discrete terms as part of the work packages. These packages present units of work at levels where the work is performed and where the effort is assignable to a single organizational element.

10. Budget overhead costs for each organizational element with a clear definition of the procedures used for allocating these costs. One option is to include a management reserve in the long- and midrange budgets as a buffer against uncertainty. The level of management reserve depends on the amount of uncertainty involved in estimating the actual cost, timing, and technological maturity of the effort required. This reserve should be factored into the budget, once again in discrete terms, as work progresses and information becomes available.

11. Define a target budget at completion as the total budget costs plus management reserve and undistributed monies.

Following this list of recommendations will make it easier to prepare and use the budget. Much can be gained by presenting a financial plan quantitatively in terms that relate the required effort to cost, timing, responsible organizational elements, and project components. Nevertheless, each organization has its own guidelines for budget preparation and presentation, so the recommendations above should be used advisedly to supplement such guidelines in areas where they are unclear or incomplete.

## 8.6 PROJECT EXECUTION: CONSUMING THE BUDGET

During the project's production phase, three processes occur simultaneously:

1. The short-range budget is translated into work and purchasing authorizations. This process generates work orders, purchase orders, and contracts with suppliers and subcontractors. It requires a feedback system that facilitates a comparison between actual progress and the original plans, and compares the actual cost of the effort performed with the budgeted cost. The exact structure of a feedback system used for project control depends on the project's structure and the organization's needs. This is explained in Chapter 11.

2. The tactical (midrange) budget is translated into a short-range budget through a rolling horizon mechanism. Cost estimates and schedules are accumulated into cost accounts as well as into apportioned effort and level of effort. This is a multistage process since the tactical budget for each period contains several short-range (operational) budget periods. Developing a new, realistic short-range budget requires detailed planning involving the integration of original project plans with reports on actual progress. The short-range budget should detail the midrange budget and in case of cost or schedule deviations, present a detailed plan for corrective action. Thus development of the operational budget is based on knowledge regarding the planned execution of activities and the project's actual status.

3. The long-range budget is gradually converted into the midrange budget. This process involves the distribution of accumulated funds, the allocation of management reserves to specific work packages, and the handling of engineering changes. Such changes are frequent in long projects. During the project execution phase, new market requirements (client needs) or new technological developments may call for modifications in the project's technological aspects. The configuration management system handles all these change requests. This system keeps track of change requests and the steps followed that lead to approval or rejection. An approved technological change may have both cost and schedule consequences. Thus the process of translating long-range budgets into midrange budgets should address all approved technological changes and their impact on the project.

Management reserve, designed to buffer uncertainty, should be consumed as soon as the results of tests and studies are available. Such results provide the basis for developing a detailed project plan translating management reserve budgets into work packages, thus reducing the level of uncertainty.

The budgeting process is ongoing. Long-term plans are translated into detailed short-term budgets, and short-term budgets are translated into work orders, purchase orders, and contracts with subcontractors and suppliers.

## 8.7 IMPORTANT POINTS IN THE BUDGETING PROCESS

The budgeting process provides an interface between organizational goals as perceived by top management, and the project managers' actions to achieve those goals. The techniques for budget preparation link the project's schedule, required resources, and net present value. The outcome provides an action framework for each organizational element. This framework integrates the budgets of the individual functional units and projects, as well as those of routine, ongoing activities into the total organizational budget.

Each project's budget is important in transforming goals into both plans and actions while providing guidelines for integration across the organizational and work breakdown structures. Management uses the budget as a communications channel to inform organizational elements of resource allocation decisions and the level of performance that is

# Reading

Stevenson, W.J. (1996) *Production/Operations Management*, 5th Edition, Irwin, pp 808-818

## WAITING—A NEW POPULAR PASTIME: MISS MANNERS

*Judith Martin*

READING

Many things in life are worth waiting for, but not all that long. Miss Manners would put a time limit on how long one should wait for salespeople to finish their conversations with each other before writing up one's order, or for a spouse who has departed with someone else to realize what a terrible mistake that was.

Nevertheless, waiting is now in a class with working as a popular pastime. A *waitologist* has estimated that the average adult spends one tenth of his or her waking moments waiting, at a minimum. There are waits for buses, banks, stores, theaters, gas stations, court cases, elevators driver's licenses, and dentist appointments.

One could easily pass one's life enduring just such basic waits. But there are also intermediary waits, such as waiting for the rain to stop, and advanced waits, such as waiting for your ship to come in. Some of these go in fashions. There was a time when all of America was waiting to be discovered by a movie talent scout in a drugstore, and now everyone is waiting for a television camera to come along and ask her to tell the world what she thinks.

*It is the elementary* and comparatively short-term wait with which Miss Manners is concerned. If you want to hear about the others, you will just have to wait.

It is perfectly correct, although not many people realize it, to refuse to wait on the telephone. When Miss Manners is asked "Can you hold on for a minute?" she often replies, "No," and it is too bad that the person on the other end ties up his own line by putting her on hold anyway, because that person has not waited for Miss Manners' reply.

One should also refuse to wait for inefficient or indefinite service. A restaurant should be able to tell you how long the wait will be, and a service person should not keep you waiting except to attend a previous customer.

*It is rude* to refuse to wait by announcing that one's needs take precedence over those of other waiting people. Miss Manners can think of no circumstances in which a person transacting the ordinary business of life can plead with legitimacy that it is more outrageous to expect him to wait than to expect it of others. "Let me go through, please—I'm in labor," perhaps, but then what are you doing at the stockings sale, anyway?

The only polite way to wait, if one must do so, is to bring one's own portable work or amusement. An unoccupied person waiting in line is by definition a potential raving maniac. A nice Jane Austen novel ready-to-go has preserved even the naturally tranquil spirits of Miss Manners. Even using conversations as a means to pass the time is dangerous, in Miss Manners' opinion. Two people quietly discussing what a shame it is to have to wait are, by the same definition, a potential mob.

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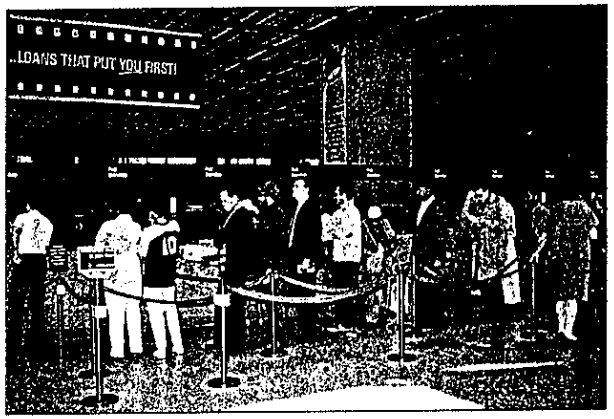
The "Miss Manners" article pokes fun at one of life's realities: having to wait in line. No doubt those waiting in line would all agree that the solution to the problem is obvious: simply add more servers or else do something to speed up service. Although both ideas may be potential solutions, there are certain subtleties that must be dealt with. For one thing, most service systems have the capacity to process more customers over the long run than they are called on to process. Hence, the problem of customers waiting is a short-term phenomenon. The other side of the coin is that at certain times the system is empty, and servers are idle, waiting for customers. Thus, by increasing the service capacity, the server idle time would increase even more. Consequently, in designing service systems, the designer must weigh the cost of providing a given level of service capacity against the potential (implicit) cost of having customers wait for service. This planning and analysis of service capacity frequently lends itself to **queuing theory**, which is a mathematical approach to the analysis of waiting lines.

Queuing theory
Mathematical approach to the analysis of waiting lines.

Waiting lines are commonly found wherever customers arrive *randomly* for services. Some examples of waiting lines we encounter in our daily lives include the lines at supermarket checkouts, fast-food restaurants, airport ticket counters, theaters, post offices, and toll booths. In many business situations, the "customers" are not people but orders waiting to be filled, trucks waiting to be unloaded, jobs waiting to be processed, or equipment awaiting repairs. Still other examples include ships waiting to dock, planes waiting to land, hospital patients waiting for a nurse, and cars waiting at a stop sign.






*First National Bank teller waiting line. Customers go into a single queue to be served by the next available teller.*

The foundation of modern queuing theory is based on studies about automatic dialing equipment made in the early part of this century by Danish telephone engineer A. K. Erlang. Prior to World War II, very few attempts were made to apply queuing theory to business problems. Since that time, queuing theory has been applied to a wide range of problems.

The mathematics of queuing can be complex; for that reason, the emphasis here will not be on the mathematics but the concepts that underlie the use of queuing in analyzing waiting-line problems. We shall rely on the use of formulas and tables for analysis.

Our discussion of queuing begins with an examination of what is perhaps the most fundamental issue in waiting line theory: Why is there waiting?

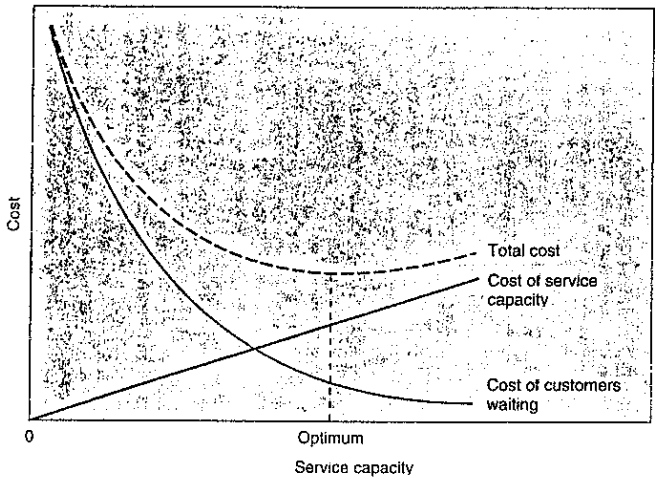
## WHY IS THERE WAITING?

Many people are surprised to learn that waiting lines tend to form even though a system is basically underloaded. For example, a fast-food restaurant may have the capacity to handle an average of 200 orders per hour and yet experience waiting lines even though the average number of orders is only 150 per hour. The key word is *average*. In reality, customers arrive at random intervals rather than at evenly spaced intervals, and some orders take longer to fill than others. In other words, both arrivals and service times exhibit a high degree of variability. As a result, the system at times becomes temporarily overloaded, giving rise to waiting lines; at other times, the system is idle because there are no customers. Thus, although a system may be *underloaded* from a *macro* standpoint, variabilities in arrivals and service mean that at times the system is *overloaded* from a *micro* standpoint. It follows that in systems where variability is minimal or nonexistent (e.g., because arrivals can be scheduled and service time is constant), waiting lines do not ordinarily form.

## GOAL OF QUEUING ANALYSIS

The goal of queuing is essentially to minimize total costs. There are two basic categories of cost in a queuing situation: those associated with customers waiting for service and those associated with capacity. Capacity costs are the costs of maintaining the ability to provide

**FIGURE 17–1**
The goal of queuing analysis is to minimize the sum of two costs: customer waiting costs and service capacity costs




service. Examples include the number of bays in a car wash, the number of checkouts in a supermarket, the number of repair people to handle equipment breakdowns, and the number of lanes on a highway. When a service facility is idle, capacity is lost since it cannot be stored. The costs of customer waiting include the salaries paid to employees while they wait for service (mechanics waiting for tools, the drivers of trucks waiting to unload), the cost of the space for waiting (size of doctor's waiting room, length of driveway at a car wash, fuel consumed by planes waiting to land), and any loss of business due to customers refusing to wait and possibly going elsewhere in the future.

A practical difficulty frequently encountered is pinning down the cost of customer waiting time, especially since major portions of that cost are not a part of accounting data. One approach often used is to treat waiting times or line lengths as a policy variable: A manager simply specifies an acceptable level of waiting and directs that capacity be established to achieve that level.

The goal of queuing analysis is to balance the cost of providing a level of service capacity with the cost of customers waiting for service. This concept is illustrated in Figure 17–1. Note that as capacity increases, its cost increases. For simplicity, the increase is shown as a linear relationship. Although a step function is often more appropriate, use of a straight line does not significantly distort the picture. As capacity increases, the number of customers waiting and the time they wait tend to decrease, thereby decreasing waiting costs. As is typical in trade-off relationships, total costs can be represented as a U-shaped curve. The goal of analysis is to identify a level of service capacity that will minimize total cost. (Unlike the situation in the inventory EOQ model, the minimum point on the total cost curve is *not* usually where the two cost lines intersect.)

## SYSTEM CHARACTERISTICS

There are numerous queuing models from which an analyst can choose. Naturally, much of the success of the analysis will depend on choosing an appropriate model. Model choice is related to the characteristics of the system under investigation. The main characteristics are:



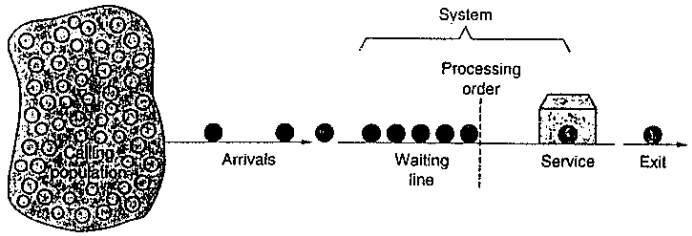



**FIGURE 17–2**
A simple queuing system

1. Population source
2. Number of servers (channels)
3. Arrival and service patterns
4. Queue discipline (order of service)

A simple queuing system is depicted in Figure 17–2.

## POPULATION SOURCE

The approach to use in analyzing a queuing problem depends on whether the potential number of customers is limited. There are two possibilities: *infinite-source* and *finite-source* populations. In an **infinite-source** situation, the potential number of customers greatly exceeds system capacity. Infinite-source situations exist whenever service is *unrestricted*. Examples are supermarkets, drugstores, banks, restaurants, theaters, amusement centers, and toll bridges. Theoretically, large numbers of customers from the "calling population" can request service at any time. When the potential number of customers is limited, a **finite-source** situation exists. An example is the repairman responsible for a certain number of machines in a company. The potential number of machines that might need repairs at any one time cannot exceed the number of machines assigned to the repairer. Similarly, an operator may be responsible for loading and unloading a bank of four machines, a nurse may be responsible for answering patient calls for a 10-bed ward, a secretary may be responsible for taking dictation from three executives, and a company shop may perform repairs as needed on the firm's 20 trucks.

Infinite source
Customer arrivals are unrestricted.

Finite source
The number of potential customers is limited.

### Number of Servers (Channels)

The capacity of queuing systems is a function of the capacity of each server and the number of servers being used. The terms *server* and **channel** are synonymous, and it is generally assumed that each channel can handle one customer at a time. Systems can be either *single-* or *multiple-channel*. (A group of servers working together as a team, such as a surgical team, is treated as a single-channel system.) Examples of single-channel systems are small grocery stores with one checkout counter, some theaters, single-bay car washes, and drive-in banks with one teller. Multiple-channel systems (those with more than one server) are commonly found in banks, at airline ticket counters, at auto service centers, and at gas stations.

Channel
A server in a service system.

A related distinction is the number of steps or *phases* in a queuing system. For example, at some college registrations, students go from desk to desk to have courses assigned and then move to final checkers and the bursar's table. Each location constitutes a separate phase where queues can (and usually do) form.

**FIGURE 17–3**
Four common variations of queuing systems

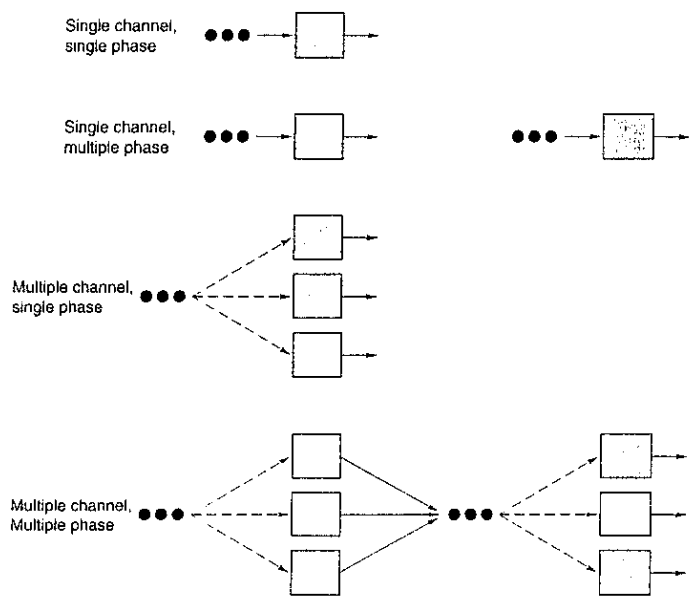



Figure 17–3 illustrates some of the most common queuing systems. Because it would not be possible to cover all of these cases in sufficient detail in the limited amount of space available here, our discussion will focus on *single-phase* systems.

## Arrival and Service Patterns

Waiting lines are a direct result of arrival and service variability. They occur because random, highly variable arrival and service patterns cause systems to be temporarily overloaded. In many instances, the variabilities can be described by theoretical distributions. In fact, the most commonly used models assume that the customer arrival *rate* can be described by a Poisson distribution and that the service *time* can be described by a negative exponential distribution. These distributions are illustrated in Figure 17–4.

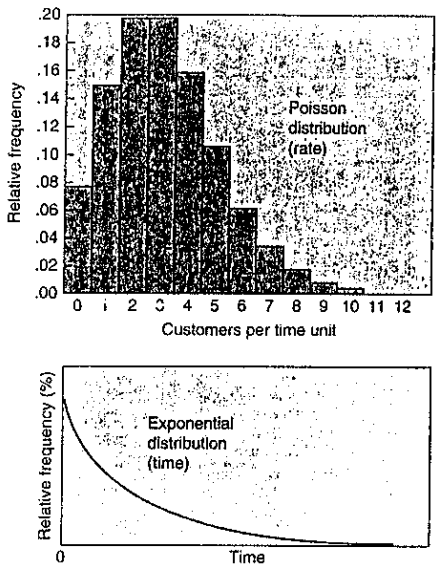
The Poisson distribution often provides a reasonably good description of customer arrivals per unit of time (e.g., per hour). Figure 17–5A illustrates how Poisson-distributed arrivals (e.g., accidents) might occur during a three-day period. In some hours, there are three or four arrivals, in other hours one or two arrivals, and in some hours no arrivals.

The negative exponential distribution often provides a reasonably good description of customer service times (e.g., first aid care for accident victims). Figure 17–5B illustrates how exponential service times might appear for the customers whose arrivals are illustrated in Figure 17–5A. Note that most service times are very short—some are close to zero—but a few require a relatively long service time. That is typical of a negative exponential distribution.

Waiting lines are most likely to occur when arrivals are bunched or when service times are particularly lengthy, and they are very likely to occur when both factors are present.



**FIGURE 17–4**
Poisson and negative exponential distributions

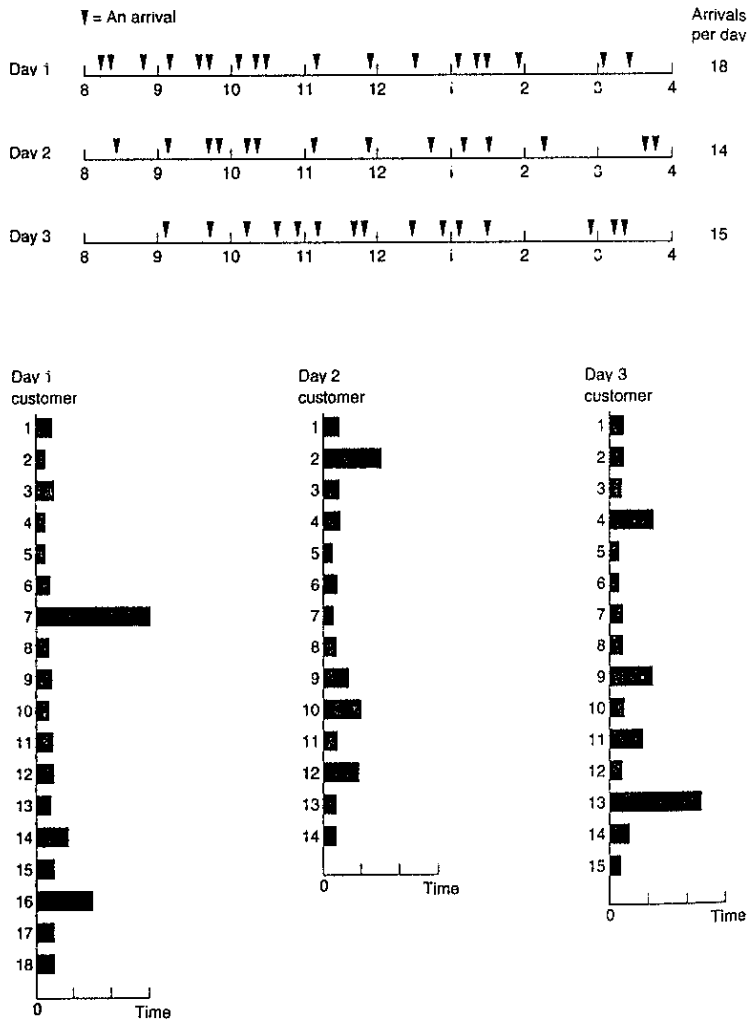



For instance, note the long service time of customer 7 on day 1, as shown in Figure 17–5B. In Figure 17–5A, the seventh customer arrived just after 10 o'clock and the next two customers arrived shortly after that, making it very likely that a waiting line formed. A similar situation occurred on day 3 with the last three customers: The relatively long service time for customer 13 (Figure 17–5B), and the short time before the next two arrivals (Figure 17A, day 3) would create (or increase the length of) a waiting line.

It is interesting to note that the Poisson and negative exponential distributions are alternate ways of presenting the same basic information. That is, if service time is exponential, then the service rate is Poisson. Similarly, if the customer arrival rate is Poisson, then the interarrival time (i.e., the time between arrivals) is exponential. For example, if a service facility can process 12 customers per hour (rate), average service time is five minutes. Similarly, if the arrival rate is 10 per hour, then the average time between arrivals is six minutes. Hence, the models described here generally require that arrival and service rates lend themselves to description using a Poisson distribution, or equivalently, that interarrival and service times lend themselves to description using a negative exponential distribution. In practice, it is necessary to verify that these assumptions are met. Sometimes this is done by collecting data and plotting them, although the preferred approach is to use a chi-square goodness-of-fit test for that purpose. A discussion of the chi-square test is beyond the scope of this text, but most basic statistics textbooks cover the topic.

Research has shown that these assumptions are often appropriate for customer arrivals but less likely to be appropriate for service. In situations where the assumptions are not reasonably satisfied, the alternatives would be to (1) develop a more suitable model, (2) search for a better (and usually more complex) existing model, or (3) resort to computer simulation. Each of these alternatives requires more effort or cost than the ones presented here.

**FIGURE 17–5**
Poisson arrivals and exponential service times



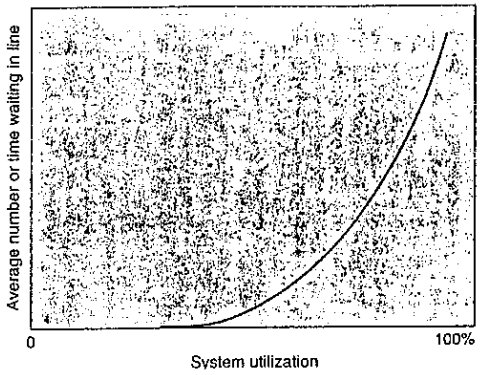

## Queue Discipline

Queue discipline
The order in which customers are processed.

**Queue discipline** refers to the order in which customers are processed. All but one of the models to be described here assume that service is provided on a *first-come, first-served* basis. This is perhaps the most commonly encountered rule. We find first-come service at banks, stores, theaters, restaurants, four-way stop signs, registration lines, and so on. Examples of systems that do not serve on a first-come basis include hospital emergency rooms, rush orders in a factory, and computer processing of programs. In these and similar situations, customers do not all represent the same waiting costs; those with the highest costs (e.g., the most seriously ill) are processed first, even though other customers may have arrived earlier.



**FIGURE 17–6**
The average number waiting in line and the average time customers wait in line increase exponentially as the system utilization increases




## MEASURES OF SYSTEM PERFORMANCE

The operations manager typically looks at five measures when evaluating existing or proposed service systems. Those measures are:

1. The average number of customers waiting, either in line or in the system.
2. The average time customers wait, either in line or in the system.
3. System utilization, which refers to the percentage of capacity utilized.
4. The implied cost of a given level of capacity and its related waiting line.
5. The probability that an arrival will have to wait for service.

Of these measures, system utilization bears some elaboration. It reflects the extent to which the servers are busy rather than idle. On the surface, it might seem that the operations manager would want to seek 100 percent utilization. However, as illustrated in Figure 17–6, increases in system utilization are achieved at the expense of increases in both the length of the waiting line and the average waiting time. In fact, these values become exceedingly large as utilization approaches 100 percent. The implication is that under normal circumstances, 100 percent utilization is not a realistic goal. Instead, the operations manager should try to achieve a system that minimizes the sum of waiting costs and capacity costs.

## QUEUING MODELS: INFINITE-SOURCE

Many queuing models are available for a manager or analyst to choose from. The discussion here includes four of the most basic and most widely used models. The purpose is to provide an exposure to a range of models rather than an extensive coverage of the field. All assume a Poisson arrival rate. Moreover, the models pertain to a system operating under *steady state* conditions; that is, they assume the average arrival and service rates are stable. The four models described are:

1. Single channel, exponential service time.
2. Single channel, constant service time.

**TABLE 17–1**
Infinite-source symbols

| Symbol | Represents |
|---|---|
| $\lambda$ | Customer arrival rate |
| $\mu$ | Service rate |
| $L_q$ | The average number of customers waiting for service |
| $L_s$ | The average number of customers in the system (waiting and/or being served) |
| $\rho$ | The system utilization |
| $W_q$ | The average time customers wait in line |
| $W_s$ | The average time customers spend in the system (waiting in line and service time) |
| $1/\mu$ | Service time |
| $P_0$ | The probability of zero units in the system |
| $P_n$ | The probability of $n$ units in the system |
| $M$ | The number of servers (channels) |
| $L_{max}$ | The maximum expected number waiting in line |

3. Multiple channel, exponential service time.
4. Multiple priority service, exponential service time.

To facilitate your use of queuing models, Table 17–1 provides a list of the symbols used for the infinite-source models.

## Basic Relationships

There are certain basic relationships that hold for all infinite-source models. Knowledge of these can be very helpful in deriving desired performance measures, given a few key values. These basic relationships are:

1. The average number being served is the ratio of arrival rate to service rate:

$$r = \frac{\lambda}{\mu} \tag{17–1}$$

[Note: $\lambda$ and $\mu$ must be in the same units (e.g., customers per hour, customers per minute)]

2. The average number in the system is the average number in line plus the average number being served:

$$L_s = L_q + r \tag{17–2}$$

3. The average time in line is the average number in line divided by the arrival rate:

$$W_q = \frac{L_q}{\lambda} \tag{17–3}$$

4. The average time in the system is the sum of the time in line plus service time:

$$W_s = W_q + \frac{1}{\mu} \tag{17–4}$$

5. System utilization is the ratio of arrival rate to service capacity:

$$\rho = \frac{\lambda}{M\mu} \tag{17–5}$$



All infinite-source models require that system utilization be less than 1.0; the models apply only to underloaded systems.

The average number waiting in line, $L_q$, is a key value because it is a determinant of some of the other measures of system performance, such as the average number in the system, the average time in line, and the average time in the system. Hence, $L_q$ will usually be one of the first values you will want to determine in problem solving.

**EXAMPLE 1**

Customers arrive at a bakery at an average rate of 18 per hour on weekday mornings. The arrival distribution can be described by a Poisson distribution with a mean of 18. Each clerk can serve a customer in an average of four minutes; this time can be described by an exponential distribution with a mean of 4.0 minutes.

*a.* What are the arrival and service *rates*?

*b.* Compute the average number of customers being served at any time.

*c.* Suppose it has been determined that the average number of customers waiting in line is 3.6. Compute the average number of customers in the system (i.e., waiting in line or being served), the average time customers wait in line, and the average time in the system.

*d.* Determine the system utilization for $M = 2$, 3, and 4 servers.

**Solution**

*a.* The arrival rate is given in the problem: $\lambda = 18$ customers per hour. The service time can be changed to a comparable *hourly* rate by first restating the time in hours and then taking its reciprocal. Thus, (4 minutes per customer)/(60 minutes per hour) = 1/15 = $1/\mu$. Its reciprocal is $\mu = 15$ customers per hour.

*b.* $r = \dfrac{\lambda}{\mu} = \dfrac{18}{15} = 1.2$ customers

*c.* Given: $L_q = 3.6$ customers.

$L_s = L_q + r = 3.6 + 1.2 = 4.8$ customers

$W_q = \dfrac{L_q}{\lambda} = \dfrac{3.6}{18} = 0.20$ hours per customer, or 0.20 hours × 60 minutes/hour = 12 minutes

$W_s$ = Waiting in line plus service

$= W_q + \dfrac{1}{\mu} = 0.20 + \dfrac{1}{15} = 0.267$ hours, or approximately 16 minutes

*d.* System utilization is $\rho = \dfrac{\lambda}{M\mu}$

For $M = 2$, $\rho = \dfrac{18}{2(15)} = .60$

For $M = 3$, $\rho = \dfrac{18}{3(15)} = .40$

For $M = 4$, $\rho = \dfrac{18}{4(15)} = .30$

Hence, as the system capacity as measured by $M\mu$ increases, the system utilization for a given arrival rate decreases.

**TABLE 17–2**
Formulas for basic single-server model

| Performance measure | Equation | |
|---|---|---|
| Average number in line | $L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$ | (17–6) |
| Probability of zero units in the system | $P_0 = 1 - \left(\frac{\lambda}{\mu}\right)$ | (17–7) |
| Probability of $n$ units in the system | $P_n = P_0\left(\frac{\lambda}{\mu}\right)^n$ | (17–8) |

## Model 1: Single Channel, Exponential Service Time

The simplest model involves a system that has one server (or a single crew). The queue discipline is first-come, first-served, and it is assumed that the customer arrival rate can be approximated by a Poisson distribution and service time by a negative exponential distribution. There is no limit on length of queue.

Table 17–2 lists the formulas for the single-channel model, which should be used in conjunction with formulas 17–1 through 17–5.

**EXAMPLE 2** An airline is planning to open a satellite ticket desk in a new shopping plaza, staffed by one ticket agent. It is estimated that requests for tickets and information will average 15 per hour, and requests will have a Poisson distribution. Service time is assumed to be exponentially distributed. Previous experience with similar satellite operations suggests that mean service time should average about three minutes per request. Determine each of the following:

*a.* System utilization.

*b.* Percent of time the server (agent) will be idle.

*c.* The expected number of customers waiting to be served.

*d.* The average time customers will spend in the system.

*e.* The probability of zero customers in the system and the probability of four customers in the system.

**Solution** ▶

$\lambda = 15$ per hour

$$\mu = \frac{1}{\text{Service time}} = \frac{1 \text{ customer}}{3 \text{ minutes}} \times 60 \text{ minutes per hour}$$

$$= 20 \text{ customers per hour}$$

*a.* $\rho = \dfrac{\lambda}{M\mu} = \dfrac{15}{1(20)} = .75$

*b.* Percentage idle time $= 1 - \rho = 1 - .75 = .25$, or 25 percent

*c.* $L_q = \dfrac{\lambda^2}{\mu(\mu - \lambda)} = \dfrac{15^2}{20(20 - 15)} = 2.25$ customers

*d.* $W_s = \dfrac{L_q}{\lambda} + \dfrac{1}{\mu} = \dfrac{2.25}{15} + \dfrac{1}{20} = 0.20$ hours, or 12 minutes

*e.* $P_0 = 1 - \dfrac{\lambda}{\mu} = 1 - \dfrac{15}{20} = .25$; $P_4 = P_0\left(\dfrac{\lambda}{\mu}\right)^4 = .25\left(\dfrac{15}{20}\right)^4 = .079$

# Reading

Schuyler, J.R. (1996) *Decision Analysis in Projects*, Project Management Institute, Pennsylvania, USA, pp. 25-31.

*Chapter Three*

# Decision Trees

*A decision model represents our understanding of a problem situation. This chapter describes what many consider the most powerful modeling and calculation technique in decision analysis.*

## Decision Tree Construction

A decision tree is a graphical representation of **expected value** (EV) calculations. The tree consists of decision, chance and terminal nodes connected by branches. This acts as a **blackboard** to develop and document our understanding of the problem and facilitates team collaboration and communication.

Conceptually, *any* decision, no matter how complex, can be analyzed with a decision tree analysis. Other alternatives, especially Monte Carlo simulation, have advantages and disadvantages for certain problems. Decision tree analysis is especially suited everyday problems where one wants to quickly pick the best alternative and proceed.

### Node Types

There are three types of **nodes** in a decision tree:

- Decision nodes, represented by squares, are variables or actions the decision maker controls.
- Chance event nodes, represented by circles, are variables or events that cannot be controlled by the decision maker.
- Terminal nodes, represented in the diagram by unconnected branches, are endpoints where outcome values are attached.

By convention, the tree is drawn chronologically from left to right. Decision tree analysis language includes colorful biological analogies. The starting decision node is called the *root*, and the radial lines are called *branches* (sometimes *twigs*). The terminal nodes are sometimes called *leaves*, an overly-complex tree bears the label, a *bushy mess*.

**Table 3.1.** Completion Time for All Activities Except Wastewater Plant

| Probability | Other Activities Complete |
|---|---|
| .30 | in 3 months |
| .40 | in 4 months |
| .30 | in 5 months |
| 1.00 | |

### Tree Annotations

The decision tree diagram is annotated with these numbers:

- *Probabilities* for each outcome branch emanating from chance nodes.
- *Outcome values*, representing present values (PV's) of the resulting cash flow stream, discounted to the date of the root decision. Sometimes, benefits and costs are placed along branches as they are realized. More commonly, all the outcome value is assigned to the terminal nodes.
- Node *expected values*, calculated during the process of solving the tree.

### Tree Calculations

Solving a decision tree is a simple back-calculation process. This is sometimes called *back-solving* or *folding back* the tree. Starting from the terminal nodes at the right, moving left, each node is solved for and labeled with its EV. These EV's are EMV's when we measure value in dollars or other currency.

Here are the **three simple rules** for solving a tree:

- At a chance node, calculate its EMV from the probabilities and values of its branches. This becomes the value of the node and the branch leading to it.
- Replace a decision node with the value of its best alternative. This is applying the EMV decision rule.
- If a cost value lies along a branch, that cost is subtracted in passing from right to left. Treat the rest of the cost as a toll to be paid when traversing the tree. (Sometimes a tree is designed to solve for EV costs, in which case a cost along a branch is added.)

## Wastewater Plant Example

In this case, a new gold mine is being developed by one firm and will be operated by another firm.

Development is nearing completion when it is discovered that water discharge contaminant levels are above those seen in the original survey samples. A regulatory agency now mandates an improved



**Figure 3.1** — Decision Node

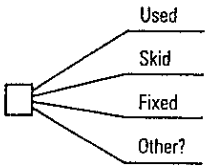



**Table 3.2** — Time to Acquire and Install Wastewater Plant

| | |
|---|---|
| **Used** | (.3, 3; .35, 4; .35, 12 months) |
| **Skid** | (.2, 4; .6, 5; .2, 6 months) |
| **Fixed** | (.2, 5; .5, 6; .3, 8 months) |

treatment facility to recover heavy metals from the mine discharge. This extended pollutant recovery capability was not designed into the nearly-completed mine facility.

The best general solution is to construct or bring in a wastewater treatment module (referred to as the "Plant" in tables and graphics). In addition to the investment and operating costs of the Plant, adding this capability has the potential to delay mine startup.

### Data Assumptions

There are uncertainties affecting the mine project completion time. For all other activities except the wastewater system, the engineers judge the completion time in three scenarios as shown in Table 3.1.

Assume that extending construction activities to meet a later start-up date will not affect costs. Further, completion times are independent of the wastewater treatment system.

Three plant alternatives are being considered:

| | |
|---|---|
| **Used** | Buy a used, skid-mounted wastewater plant |
| **Skid** | Buy a new, skid-mounted plant |
| **Fixed** | Buy a new, fixed plant |

Figure 3.1 shows how the root decision node will appear, adding a branch for another alternative to be evaluated later.

Although costing more initially, the Skid plant costs less to operate and is faster to install, plus is likely to have greater salvage value at mine abandonment than a Used plant. A Fixed plant costs less to buy and operate than a skid-mounted plant but requires more time to install. Clearly, trade-offs will be necessary in making the decision.

**Figure 3.2** — Chance Node Example

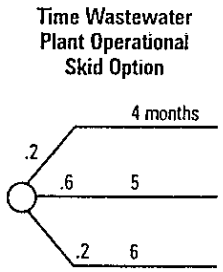



**Table 3.3** — Plant Cost Information.
(All values are pre-tax $000's.)

| Expenditure | Used | Skid | Fixed |
|---|---|---|---|
| Acquisition + Installation | $650 | $1480 | $1150 |
| Salvage Value | $0 | $600 | $200 |
| Operating Costs Per Month | $8.0 | $6.3 | $5.0 |

Times for the various acquisition options are judged with three weighted scenarios. Between the vendors and the project engineers, three-level discrete distributions are assessed as shown in Table 3.2.

These pairs of points represent outcomes values (second in each pair) with their associated probabilities (first value, a decimal, in each pair). This *lottery notation* is a way of expressing a discrete chance event. The other mine activities are *independent* of the wastewater plant. Figure 3.2 illustrates what a Time Plant Operational chance node looks like for the skid option .

An important consideration is the cost of delaying the mine startup. In this case, the *opportunity loss* is the foregone asset value due to increased development costs and delaying mine production. Assume that, from the project feasibility model, the project team determines that changes to mine startup date are valued at $150,000 per month (pre-tax). Early completions have the opposite effect. The mine is projected to operate for six years. Other information about the options are shown in Table 3.3. Assume these values are known well enough that single-point estimates can be used.

Over half of a typical custom evaluation involves developing a **project cash flow model**. The model provides the outcome value for each scenario: combination of decisions and chance event outcomes.



**Figure 3.3** — Evaluating Plant Options

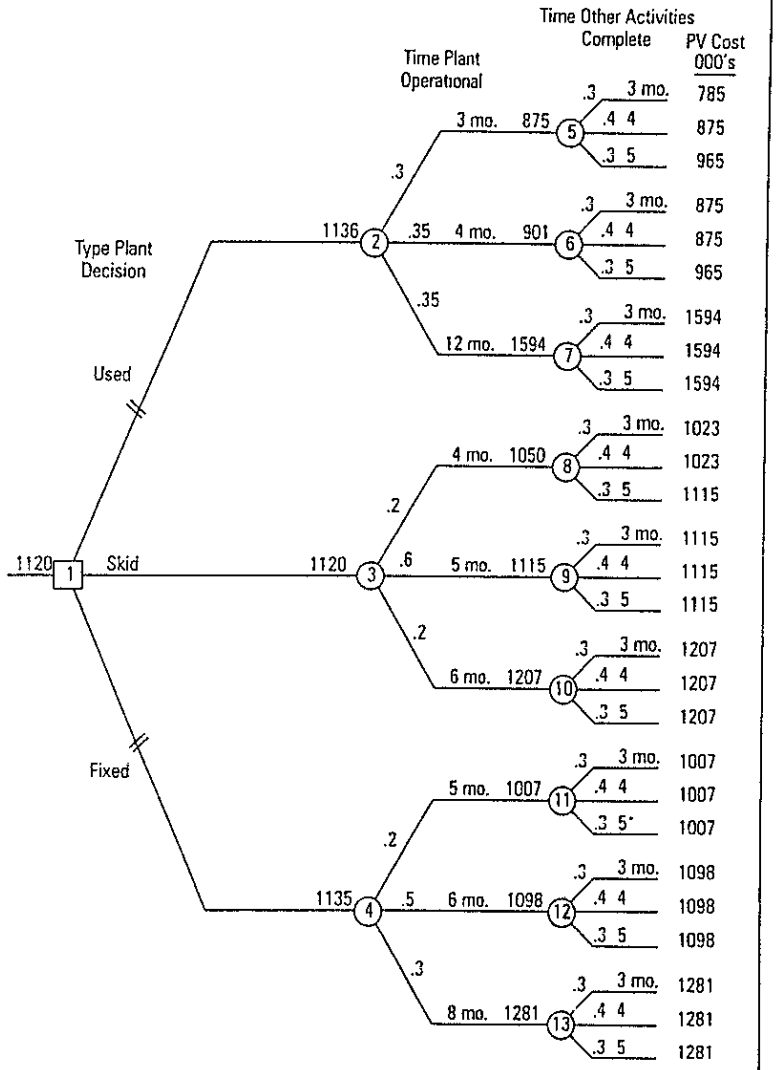


**Table 3.4.** Back-Solving the Tree

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| EV(5) | = | .3(785) | + | .4(875) | + | .3(965) | = | $875,000 |
| EV(6) | = | .3(875) | + | .4(875) | + | .3(965) | = | 901,000 |
| EV(7) | = | .3(1594) | + | .4(1594) | + | .3(1594) | = | 1,594,000 |
| EV(8) | = | .3(1023) | + | .4(1023) | + | .3(1115) | = | 1,050,000 |
| EV(9) | = | .3(1115) | + | .4(1115) | + | .3(1115) | = | 1,115,000 |
| EV(10) | = | .3(1207) | + | .4(1207) | + | .3(1207) | = | 1,207,000 |
| EV(11) | = | .3(1007) | + | .4(1007) | + | .3(1007) | = | 1,007,000 |
| EV(12) | = | .3(1098) | + | .4(1098) | + | .3(1098) | = | 1,098,000 |
| EV(13) | = | .3(1281) | + | .4(1281) | + | .3(1281) | = | 1,281,000 |
| EV(2) | = | .3 EV(5) | + | .35 EV(6) | + | .35 EV(7) | | |
| | = | .3(875) | + | .35(901) | + | .35(1594) | = | $1,136,000 |
| EV(3) | = | .2 EV(8) | + | .6 EV(9) | + | .2 EV(10) | | |
| | = | .2(1050) | + | .6(1115) | + | .2(1207) | = | $1,120,000 |
| EV(4) | = | .2 EV(11) | + | .5 EV(12) | + | .3 EV(13) | | |
| | = | .2(1007) | + | .5(1098) | + | .3(1281) | = | $1,135,000 |

And applying the EV decision rule:

EV(1) = Minimum{EV(2), EV(3), EV(4)}
= Minimum{1136, 1120, 1135} = $1,120,000

Values are shown to the nearest $1,000, although calculations were performed with greater precision.

The model underlying the values shown in Figure 3.3 include, in addition to the assumptions in Tables 3.1-3.3, such items as inflation, cost of capital, depreciation, and taxes.

### Try Your Intuition

If you have experience in problems of this sort, perhaps you can judge the best alternative by inspection. Try estimating EV costs for each option. What is the difference in EV cost between the first choice and the next best alternative?

For most of us, even this small problem is much too complex to internalize in our heads. The plant choice is not obvious because each alternative has advantages:

**Used** Lowest initial cost.

**Skid** Fastest and lowest-risk acquisition time, medium operating costs, highest salvage value.

**Fixed** Lowest operating costs, medium investment.

No single alternative dominates across all attributes. Most of us need an analytic tool to have confidence in our selection.



### Evaluating Options

The *appraisal approach* of decision analysis is a logical way to evaluate the three plant acquisition alternatives. Figure 3.3 shows the complete decision tree model: terminal nodes (right column) show outcomes if the respective tree path is realized; the outcome value is PV costs. Again, these terminal values are obtained from a cash flow projection model. Since all monetary values are costs, one may work with EV costs instead of EMV's; minimizing EV cost is exactly equivalent to maximizing EMV.

The root node is the Type Plant decision. There are two chance events affecting outcome value: Time Plant Becomes Operational *and* Time Other Activities Complete. The latest event controls when the mine development project is complete. These chance event outcomes are annotated with labels (months to complete) and the probability of the respective outcome. Each chance and decision node is annotated with its EV cost.

The three alternatives are evaluated by back-solving the decision tree. The nodes have been numbered for illustrating the calculations. Table 3.4 shows the sequence and components of node EV calculations.

Note there are fewer calculations at each column of nodes in progressing from right to left through the tree. For large trees, the progressive thinning of branches provides considerable **calculation efficiency** (as compared to a payoff table approach). Acquiring a Skid plant ($1,120,000) appears the best of the three alternatives, although its superiority is slight ($16,000). The "cut" marks on branches indicate inferior alternatives that have been "pruned."

## Summary

Decision tree analysis is a convenient way to analyze project decisions having one or several important uncertainties. Probability distributions are used to encode judgments about risk and uncertainty. For all but the simplest of problems, such decision models greatly bolster our intuition.

A single value measure, gauging benefits or progress toward the organization's objective, is a central idea in decision analysis. Money is a convenient measurement scale for most purposes. The Wastewater Plant example combined cost, schedule and performance criteria into a single monetary value measure, EV costs:

- *Schedule* was translated into cost-equivalents by recognizing the value lost due to project delay.
- *Performance* was recognized by different plant operating costs during the mine life.

Many practitioners believe that insights gained into decision problems are more important than the numerical results. Further comfort comes from credible quantitative analysis results.

# Reading

Cassimatis, P. (1992) *A Concise Introduction to Engineering Economics,* E&FN SPON, pp 206-221.

# 13 Cost analysis models

In this chapter we focus on applications of cost analysis to capital investment decisions. We first examine the concept of optimizing benefits by minimizing costs. Next we consider the method of life-cycle cost analysis in evaluating investment proposals for products and capital assets. Finally, we discuss the use of break-even cost analysis for the selection of the best among multiple alternative investments.

## 13.1 Minimum cost analysis

In evaluating alternative investments it is possible to find the best alternative on the basis of minimum cost rather than maximum benefit. The decision is justifiable, if the benefit of each alternative is expected to be the same. Similarly, when considering the optimum size of a project, such as a piece of machinery or equipment, it is proper to determine its minimum cost over a range of relevant values of the independent variable, i.e. size of capacity, provided that the expected benefit is the same. In terms of economic theory, the total cost of a project can be said to be a function of the sum of two cost functions, one which increases directly with the independent variable, and the other decreasing as the independent variable increases as follows:

$$TC=C_1+C_2$$

where

$$C_1=f(X), \quad C_2=f\left(\frac{1}{X}\right)$$

One of the most frequently encountered total cost functions in engineering economy takes the form

$$TC=a+bX+\frac{c}{X}$$

where $X$ is an independent variable, $a$ is either zero or a fixed cost, and $b$ and $c$ are constants. As shown in Figure 13.1, the increasing cost function is assumed to be linear, the decreasing function is nonlinear, and their sum, which yields the total cost function, is a polynomial. The lowest point of the total cost curve is the minimum cost of the project and corresponds to a



DETERMINATION OF OPTIMUM SIZE OF PROJECT

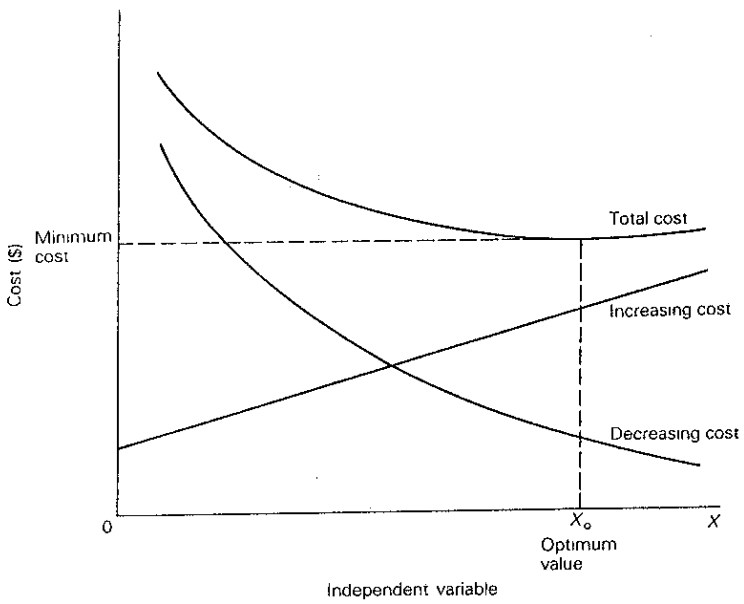



**Figure 13.1** Minimum cost analysis functions.

value of the independent variable that defines the optimum size or capacity of the project.

Mathematically, the optimum value of the independent variable, $X_0$, is obtained by differentiating the total cost function and setting it equal to zero:

$$\frac{dTC}{dX}=b-\frac{C}{X^2}=0, \quad X_0=\sqrt{\frac{c}{b}}$$

The minimum cost in dollars is then found by substituting $X_0$ in the total cost equation.

A classic application of this model, first observed by Lord Kelvin, is that the economic size of a conductor occurs when the annual investment cost is equal to the annual cost of lost energy; this is known as Kelvin's Law.

## 13.2 Determination of optimum size of project

A company operates a chain of supermarkets in a city where rental space is limited and expensive. The management is at present considering opening a

new store and wants to determine the optimum amount of floor space based on the experience of its other supermarkets. A statistical analysis of current data indicates that the annual equivalent cost of the building and equipment is

$$C_1 = 1.25 + 0.64X$$

the operating and maintenance cost per year is

$$C_2 = \frac{31.5}{X}$$

and total cost per supermarket per year is

$$TC = C_1 + C_2$$

where $C$ is in million dollars and $X$ is in tens of thousands of square feet of floor space. The optimum size of the new supermarket can be estimated as follows:

$$TC = 1.25 + 0.64X + \frac{31.5}{X}$$

$$\frac{dTC}{dX} = 0.64 - \frac{31.5}{X^2} = 0,$$

$$X = \sqrt{31.5/0.64} = 7.02 \text{ thousand square feet}$$

Therefore, the optimum floor space for a new supermarket is 7,000 square feet. The corresponding total cost would be

$$TC = 1.25 + 0.64\ (7) + \frac{31.5}{7} = \$10.23 \text{ million per year}$$

The results are also shown in Table 13.1 and Figure 13.2. Note the amount of the fixed cost, $1.25 million, does not enter in the computation of the optimum value of the independent variable, in this case size of the project, but it is included in computing the total minimum cost of the project.

## 13.3 Minimum cost among alternatives

The preceding analysis assumed that the cost of a project is a continuous function of a major independent variable and that given sufficient statistical





**Table 13.1** Determination of optimum size of project.

| Size of project (square feet) (thousands) $X$ | Annual equivalent cost of P & E ($ millions) $C_1$ | Annual operating and maintenance ($ millions) $C_2$ | Annual total cost ($ millions) $TC$ |
|---|---|---|---|
| 0 | 1.25 | 0 | 1.25 |
| 1 | 1.89 | 31.50 | 33.39 |
| 2 | 2.53 | 15.75 | 18.28 |
| 3 | 3.17 | 10.50 | 13.67 |
| 4 | 3.81 | 7.88 | 11.69 |
| 5 | 4.45 | 6.30 | 10.75 |
| 6 | 5.09 | 5.25 | 10.34 |
| 7 | 5.73 | 4.50 | 10.23* |
| 8 | 6.37 | 3.94 | 10.31 |
| 9 | 7.01 | 3.50 | 10.51 |
| 10 | 7.65 | 3.15 | 10.80 |

*Minimum total cost per year corresponds to project size of 7,000 square feet.

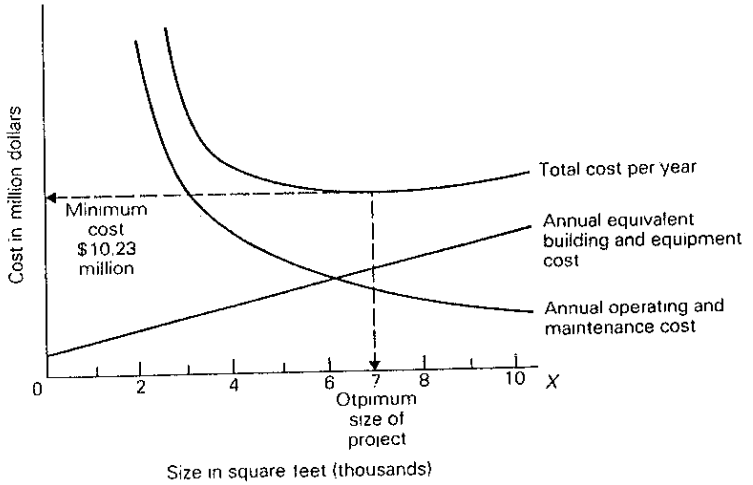



**Figure 13.2** Minimum cost analysis of project.

observations cost functions can be derived using regression methods. Frequently the cost of a project and its size or capacity can be estimated only in a few discrete amounts but over a relevant range of values. In such cases the minimum cost of the project can be found by tabulating and then adding together its increasing and decreasing components.

**Table 13.2** Determination of minimum cost alternative.

| Size (horsepower) | Annual equivalent cost ($) | Annual operating cost ($) | Annual total cost ($) |
|---|---|---|---|
| 15 | 1,055 | 5,256 | 6,311 |
| 30 | 1,319 | 4,161 | 5,480 |
| 60 | 1,847 | 3,139 | 4,986* |
| 100 | 2,638 | 2,555 | 5,193 |
| 150 | 3,429 | 2,190 | 5,619 |

*Minimum cost alternative is 60 horsepower.

Suppose, for example, that an industrial plant is considering the purchase of an electric motor and five types are available. Each motor is expected to have a useful life of 5 years with zero salvage value and the firm's cost of capital is 10%. The prices of the motors and their operating costs are shown below:

| *Size of motor (horsepower)* | *Purchase price* ($) | *Operating cost (per horsepower-hour)* ($) |
|---|---|---|
| 15 | 4,000 | 0.072 |
| 30 | 5,000 | 0.057 |
| 60 | 7,000 | 0.043 |
| 100 | 10,000 | 0.035 |
| 150 | 13,000 | 0.030 |

It is expected that the motor will be operated 1,460 horsepower-hours per week, 50 weeks per year. From a performance standpoint any one of these motors would be acceptable. Therefore the best alternative is the one with the minimum total annual cost. In this case, the increasing cost component of the total annual cost function is obtained by calculating the annual equivalent cost of each motor.

$$AE = P(^{A/P,\, i,\, n})$$

The decreasing component of the cost function is obtained by finding the annual operating cost of each motor:

$AO$=1,460×50=73,000 horsepower-hours per year
times the cost per horsepower-hour

The results are tabulated in Table 13.2. Notice that the total annual cost is derived by adding the annual equivalent cost to the annual operating cost





for each size of motor. It can be seen that the minimum cost alternative is the 60-horsepower motor

$$TC = \$7{,}000\ (P/A,\ 10,\ 5)(0.2638) + 73{,}000 \text{ hp-hrs } (\$0.043) = \$4{,}986 \text{ per year}$$

## 13.4 Life-cycle cost analysis

Life-cycle cost analysis involves the consideration of all relevant costs of a project, beginning with the planning and design stage, through development and testing, production operation, and maintenance to the final stage of sale or disposal. It is widely used under government contracts, such as defense procurement and public works, in order to minimize the total cost of the project over its useful life. In business, life-cycle cost analysis has been used to justify a product's price *vis-à-vis* its competition's, when all other costs associated with owning the product over its lifetime are taken into consideration. When a consumer is faced with the choice between durable goods, such as automobiles or refrigerators, the real economic cost of each alternative can be established, using present worth analysis, by adding to the product's price the present value of all other expenses required to operate and maintain that product over its useful life, or by calculating the equivalent annual cost to own, operate, and maintain the product during its lifetime.

## 13.5 Life-cycle analysis of products

The enormous increase in the price of energy since the 1970s has brought about energy conservation guidelines from the government and made consumers more aware of the relative energy efficiency of durable goods and industrial equipment. Consequently, manufacturers of energy-consuming products have responded by redesigning them to reduce their energy cost, although product prices have increased. Through market promotions and advertising manufacturers argue that the life-cycle cost of the product has not increased in real terms.

As an example, a firm has been producing a type of industrial equipment at $450 and selling it at $500 per unit. The product has a projected useful life of 5 years and its estimated annual energy input is 2,000 kilowatt-hours. The annual maintenance cost is expected to rise 10% each year, starting at $50 at the end of the first year, and the cost of electricity is $0.15 per kilowatt-hour. The engineering department has redesigned the product so that its energy requirements will be 60% of those of the old design, and the maintenance cost is expected to be $40 the first year and to rise 5% each year thereafter. Because the cost of the new product will be $100 higher than that of the old

**Table 13.3** Life-cycle cost analysis of a product ($).

| | | |
|---|---|---|
| **A. Old design** | | |
| Price | | 500.00 |
| Operating cost: | | |
| Year: 1 | 50.000 (0.8929)=44.65 | |
| 2 | 55.000 (0.7972)=43.85 | |
| 3 | 60.500 (0.7118)=43.06 | |
| 4 | 66.550 (0.6355)=42.29 | |
| 5 | 73.205 (0.5674)=41.54 | |
| | | 215.39 |
| Energy cost: | 0.15 (2,000) (3.6048)= | 1,081.44 |
| | Life-cycle cost | 1,796.83 |
| **B. New design** | | |
| Price | | 650.00 |
| Operating cost: | | |
| Year: 1 | 40.000 (0.8929)=35.72 | |
| 2 | 42.000 (0.7972)=33.48 | |
| 3 | 44.100 (0.7118)=31.39 | |
| 4 | 46.305 (0.6355)=29.43 | |
| 5 | 48.620 (0.5674)=27.59 | |
| | | 157.61 |
| Energy cost: | 0.15 (1,200) (3.6048)= | 648.86 |
| | Life-cycle cost | 1,456.47 |

design, its price has been set at $650 per unit. Assuming that the average interest rate is 12%, management argues that the new product is cheaper to users.

Applying life-cycle cost analysis to the product, the results in Table 13.3 indicate that the redesigned product will indeed be more economical to the user. Notice that under the old design and at a price of $500, the life-cycle cost to the user was $1,797. The life-cycle cost of the new design is $1,456 despite the fact that the price has been increased to $650.

## 13.6 Break-even cost analysis

Once a capital asset has been purchased to help produce a product or perform a service, its cost to the firm consists of two elements: fixed cost and variable cost. The fixed cost of an asset is established by calculating the annual equivalent cost of capital recovery, given its economic life, salvage





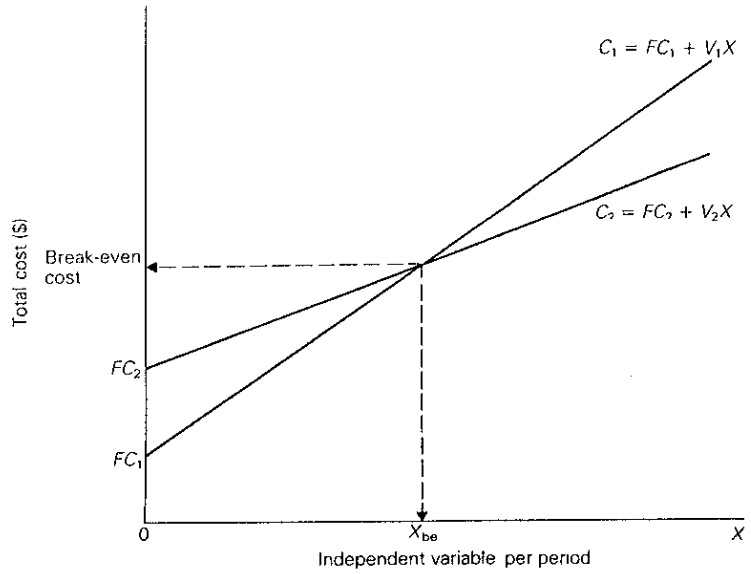



**Figure 13.3** Break-even cost analysis chart.

value, and the firm's cost of capital, plus other annual fixed expenses, if any. The variable cost consists of the annual expenditures associated with operating the asset based on the number of hours of operation, the volume of output, or some other variable that measures the use of the asset.

Given two alternatives having a common operating variable, there is a value for which the total annual cost of each alternative is the same, known as the *break-even point*. Suppose, for example, that a firm is considering two proposals and their total annual equivalent costs are expressed by the following linear equations:

$$C_1 = FC_1 + V_1 \cdot X$$

$$C = FC_2 + V_2 \cdot X$$

where $FC$ is total fixed cost per year, $X$ is the value of the common independent variable per year, and $V$ is the average variable cost per unit of $X$. Break-even occurs when the total annual cost of one proposal is equal to that of the other, or

$$C_1 = C_2$$

$$FC_1 + V_1 \cdot X = FC_2 + V_2 \cdot X$$

or

$$X_{be} = \frac{FC_2 - FC_1}{V_1 - V_2}$$

If the cost equations are plotted as in Figure 13.3 the break-even point is defined by the intersection of two lines and its value is expressed in terms of $X$, the independent value, on the horizontal axis and in terms of total annual equivalent cost, in dollars, on the vertical axis.

## 13.7 Break-even cost of two proposals

The manager of a manufacturing plant must choose between two types of furnace for the ceramic components of its products.

One operates on coal and costs $10,000 with an estimated salvage value of $500 at the end of 6 years. Its projected annual maintenance cost is $300 and operating cost is estimated at $1.90 per hour.

The alternative operates on electricity at an hourly cost of $1.25 and annual maintenance expense of $100. Its initial cost is $15,000 and estimated salvage value is $1,000 after 6 years.

If the cost of capital is 10%, what is the break-even point of the two alternatives?

It is apparent in this case that, because the common independent variable of the two types of furnace under consideration is number of hours of operation per year, the solution can be obtained mathematically by setting the total cost functions equal to one another and solving for hours per year.

$$C_1 = C_2$$

$$FC_1 + V_1 \cdot H = FC_2 + V_2 \cdot H$$

or

$$H_{be} = \frac{FC_2 - FC_1}{V_1 - V_2}$$

where $H_{be}$ is the break-even point in hours per year, $FC$ is annual fixed cost in dollars, and $V$ is average variable cost in dollars per hour of operation.

Thus, the annual cost of the coal-fired furnace is





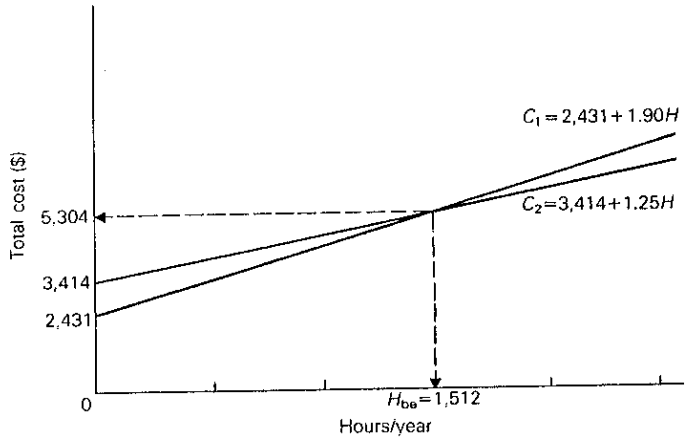



**Figure 13.4** Break-even cost of two alternatives.

$$C_1 = \$10{,}000\ (A/P, 10, 6)\ (0.2296) - \$500\ (A/F, 10, 6)\ (0.1296) + \$200 + \$1.90H$$
$$= \$2{,}431 + \$1.90H$$

The annual cost of the electric furnace is

$$C_2 = \$15{,}000\ (A/P, 10, 6)\ (0.2296) - \$1{,}000\ (A/F, 10, 6)\ (0.1296) + \$100 + \$1.25H$$

$$= \$3{,}414 + \$1.25H$$

The break-even point of operation is

$$H_{be} = \frac{\$3{,}414 - \$2{,}431}{\$1.90 - \$1.25} = 1{,}512 \text{ hours per year.}$$

Substituting $H = 1{,}512$ into the cost equations gives

$$C_1 = \$2{,}431 + \$1.90\ (1{,}512) = \$5{,}304 \text{ per year}$$

$$C_2 = \$3{,}414 + \$1.25\ (1{,}512) = \$5{,}304 \text{ per year}$$

and we find the break-even annual equivalent cost of the two alternatives. The results can be illustrated in Figure 13.4. Assuming that the annual hours of operation are expected to be less than 1,512, i.e. below the break-even

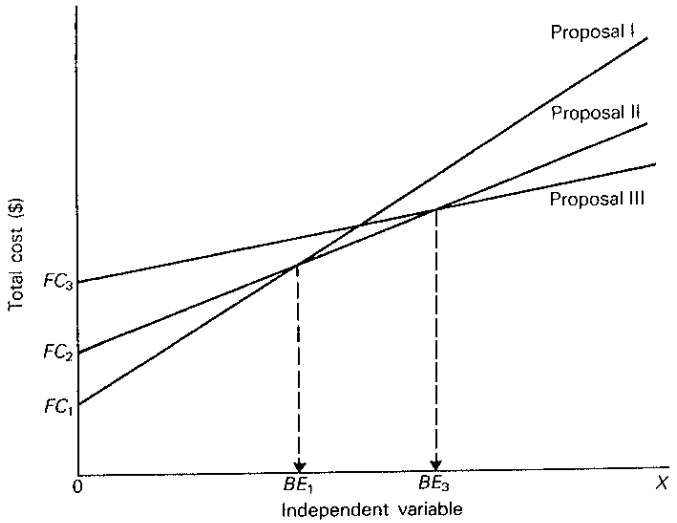



**Figure 13.5** Break-even cost of multiple alternatives.

point, the coal furnace should be selected. Above the break-even point, the electric furnace is a better investment.

## 13.8 Break-even of multiple alternatives

It is possible that the choice of the best alternative may depend on the break-even points of several alternative proposals, as shown in Figure 13.5. The solution is obtained by calculating the break-even point of two alternatives at a time. Then, depending on the expected range of values of the independent variable the most economical alternative is selected. For example, if the expected value for $X$ is less than the first break-even point, proposal I is selected.

If the expected value of $X$ is greater than the first break-even point, but less than the third break-even point, proposal II is the best alternative. Proposal III should be selected if the expected value of $X$ is greater than the third break-even point.

## 13.9 Make-or-buy decisions

In an increasingly competitive environment, business firms must frequently decide whether to produce a product or purchase it from a supplier. The





choice is dictated by increases in the costs of labor, materials, or capital, by changes in the company's market share, or by technological change. Consider, for example, the dilemma a manufacturing firm faces when it discovers that a component required for one of its products is available, at a price lower than the cost of producing it, from a domestic or foreign firm. Sometimes the amount of output required may not be large enough to yield economies of scale. At other times the demand for a certain item may exceed the firm's production capacity. In these and similar cases, a decision must be made whether to produce or purchase the required product. Make-or-buy decisions are increasingly common and can be resolved using economic analysis by comparing the costs and benefits of producing versus purchasing the item in question. The cost-to-buy is often a function of the price and quantity of the product in *linear* form:

$$C_b = PQ$$

where the price, $P$, in dollars is constant regardless of the number of units purchased, $Q$, over a specified period of time, usually a year. When in competitive markets price discounts are available, the cost-to-buy function is *nonlinear* such as the following:

$$C_b = PQ - dQ^2$$

where $dQ^2$ reflects the discount applied to the price at different levels of volume.

The cost-to-make consists of fixed and variable costs in linear or non-linear form, depending on the underlying production function, such as those discussed in Chapter 12.

$$C_m = a + bQ$$

or

$$C_m = a + bQ + CQ^2$$

where $a$ is the annual equivalent fixed cost and $Q$ is the number of units produced per year.

The decision of whether to make or buy can be made by comparing the appropriate cost functions using break-even analysis. The break-even point defines the level of output where the cost to produce is equal to the cost to purchase, as shown in Figure 13.6. At outputs below the break-even point the cost to buy is lower than the cost to make. At volumes above the break-even point producing the product is more economical.

*Make-or-buy economic orders*

In order to produce a product, supplies must be purchased in advance to be available for a smooth and continuous operation of the manufacturing process.

The cost of procuring and holding supplies for production, known as inventory cost, requires also minimum-cost analysis. The following is a description of the economic variables involved in inventory decisions.

*Purchase cost* This is the cost of buying the annual demand required of a certain item at a given price, or $DP$, where $D$ is the total number of units of the item to be purchased per year and $P$ is the price per unit.

*Procurement cost* The cost of placing and expediting each order with a supplier is expressed as follows:

$$\frac{D}{Q}p$$

where $Q$ is the size of the order (number of units per order) and $p$ is the cost to place an order.

*Holding cost* This is also known as carrying cost or storage cost and is measured by

$$\frac{Q}{2}h$$

where $h$ is the cost of holding a unit of inventory per year and $Q/2$ is the average inventory in storage.

*Opportunity cost* Items held in inventory cause an opportunity cost to the enterprise, i.e. capital is tied up, and, therefore, add to the holding cost of inventory as follows:

$$\frac{PQi}{2}$$

where $i$ is the cost of capital.

*Total cost of inventory* By adding all of the preceding cost elements, the total cost of inventory is specified:

$$TC=DP+\frac{D}{Q}p+\frac{(h+iP)}{2}Q$$





Notice that the only independent variable on the right-hand side of the equation is $Q$. All others are constant for a given period, usually a year. Differentiating the total cost function and setting it equal to zero, we obtain

$$\frac{dTC}{dQ}=-\frac{Dp}{Q^2}+\frac{h+iP}{2}=0$$

$$Q_b=\sqrt{\frac{2Dp}{h+iP}}$$

$Q_b$ is the economic order quantity (EOQ) for buying. When $Q$ is substituted in the total cost equation, we obtain the minimum cost of inventory per year.

*Economic production quantity* When a part or a component of a product can be produced internally, management must determine the optimum production quantity of items to be supplied to the assembly department. In this case, the annual rate of production, $R$, may exceed the annual rate of its demand, $D$, and consequently inventories will accumulate. For make-decisions the formula for optimum quantity is modified as follows:

$$Q_m=\sqrt{\frac{2DS}{h\left(1-\frac{D}{R}\right)}}$$

where $p$ is the set-up cost of machinery and equipment for each production run, and $Q_m$ is the economic production quantity (EPQ) per production run to make the item.

## 13.10 Example of make-or-buy decision

A manufacturer of a household appliance usually makes all of its components including the thermostat. Recently, several firms have begun to market this type of thermostat at competitive prices. The best offer was made by a reliable supplier that can deliver the item according to the price–quantity schedule shown:

$$Q=200-20P$$

From this the following cost equation is obtained:

$$C_b=10Q-0.05Q^2$$

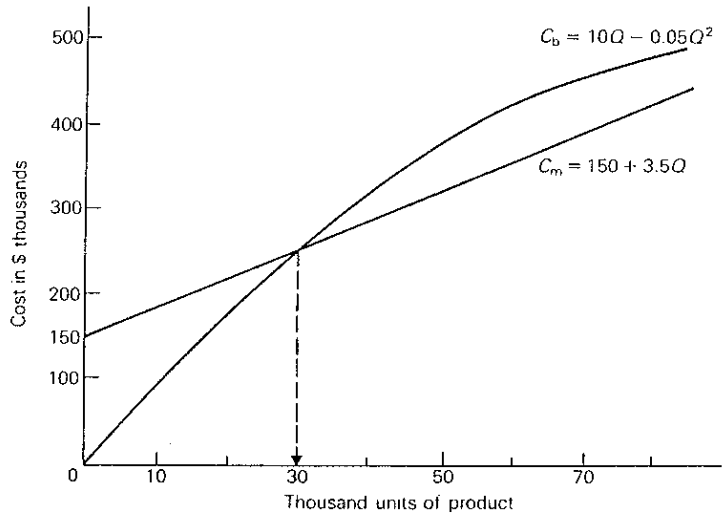



**Figure 13.6** Make-or-buy break-even.

where $C_b$ is the cost to buy in thousands of dollars and $Q$ is the number of units in thousands. The manufacturing firm estimates that the cost to make this item in its own plant has the following cost function:

$$C_m = 150 + 3.5Q$$

where $C_m$ is the total cost to make in thousands of dollars and $Q$ is the number of units in thousands.

The *break-even point* is found by setting the two cost equations equal to one another and solving for $Q$:

$$150 + 3.5Q = 10Q - 0.05Q^2$$

$$0.05Q^2 - 6.5Q + 150 = 0$$

$$Q = \frac{6.5 \pm \sqrt{(42.25 - 30)}}{0.10} = \frac{6.5 - 3.5}{0.10} = 30 \text{ (thousand units)}$$

The two cost functions and their break-even point are shown in Figure 13.6.

If annual demand for this product is less than 30,000 units it is more economical to buy it. However, if the expected range of production exceeds





30,000 per year, the firm would reduce its cost by manufacturing the product.

## Problems

1 Hermes Products Ltd. is planning the construction of a new warehouse in the southeastern region of the United States for storage and distribution of home electronics products to retail establishments. Based on statistical data from other warehouses, the engineering department estimates that the annual equivalent cost of the building and equipment is expressed by the following linear cost equation:

$$C_1 = 9.50 + 5.15X$$

and the annual cost of operation and maintenance is measured by

$$C_2 = \frac{82.5}{X}$$

where $C$ is cost in million dollars per year and $X$ is floor space in hundreds of thousands of square feet.

(a) Determine the optimum size of warehouse.
(b) Calculate the total annual cost that corresponds to the optimum size of warehouse.
(c) Compute the total annual cost of the warehouse for the following floor space in thousands of square feet: 100, 200, 300, 400, 500; and find the optimum size of the project. Plot the data in a diagram.

2 Hercules Buildings Inc., a producer of prefabricated warehouses, proposes to deliver and install a prefabricated warehouse to Hermes Products, of the preceding problem, that would have the following annual equivalent cost function

$$C_2 = \frac{84.9}{X} + 6.2X + 7.0$$

where $C_2$ is annual cost in million dollars and $X$ is floor space in hundreds of thousands of square feet.

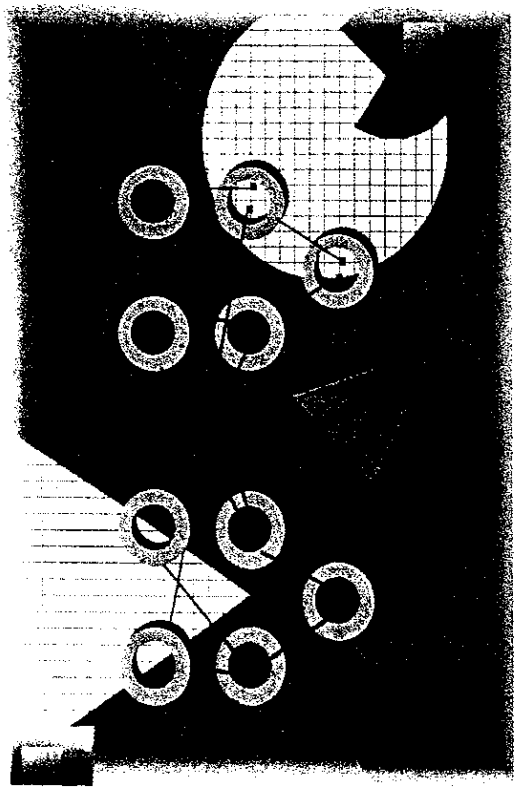
Assuming the prefabricated warehouses were equally satisfactory to Hercules:

(a) Calculate the optimum size of this proposed warehouse, and its corresponding total annual cost.
(b) If the amount of floor space required is 370,000 square feet, which is the better alternative?

# Reading

Taylor, B.W. (1999) *Introduction to Management Science*, 6th Edition, Prentice Hall, Inc., New Jersey, pp. 775-791.

# 18 Inventory Management



## Elements of Inventory Management
The Role of Inventory • Demand • Inventory Costs

## Inventory Control Systems
Continuous Inventory Systems • Periodic Inventory Systems • TIME OUT for Ford Harris

## Economic Order Quantity Models

## The Basic EOQ Model
Carrying Cost • Ordering Cost • Total Inventory Cost • EOQ Analysis over Time

## The EOQ Model with Noninstantaneous Receipt

## The EOQ Model with Shortages
Management Science Application: Parts Inventory Management at IBM

## EOQ Analysis with QM for Windows

## EOQ Analysis with Excel and Excel QM

## Quantity Discounts
Quantity Discounts with Constant Carrying Costs • Quantity Discounts with Carrying Costs as a Percentage of Price • Quantity Discount Model Solution with QM for Windows

## Reorder Point
Safety Stocks

## Determining Safety Stocks Using Service Levels
Reorder Point with Variable Demand • Management Science Application: Inventory Control for Deskjet Printers at Hewlett-Packard • Determining the Reorder Point with Excel • Reorder Point with Variable Lead Time • Reorder Point with Variable Demand and Lead Time

## Order Quantity for a Periodic Inventory System
Order Quantity with Variable Demand • Determining the Order Quantity for the Fixed-Period Model with Excel

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Summary • References • Example Problem Solution • Questions • Problems • Case Problems

Inventory analysis is one of the most popular topics in management science. One reason is that almost all types of business organizations have inventory. Although we tend to think of inventory only in terms of stock on a store shelf, it can take on a variety of forms, such as partially finished products at different stages of a manufacturing process, raw materials, resources, labor, or cash. In addition, the purpose of inventory is not always simply to meet customer demand. For example, companies frequently stock large inventories of raw materials as a hedge against strikes. Whatever form inventory takes or whatever its purpose, it often represents a significant cost to a business firm. It is estimated that the average annual cost of manufactured goods inventory in the United States is approximately 30% of the total value of the inventory. Thus, if a company has $10 million worth of products in inventory, the cost of holding the inventory (including insurance, obsolescence, depreciation, interest, opportunity costs, storage costs, etc.) would be approximately $3 million. If the amount of inventory could be reduced by half to $5 million, then $1.5 million would be saved in inventory costs, a significant cost reduction.

This chapter will include the classic economic order quantity models, which represent the most basic and fundamental form of inventory analysis. These models provide a means for determining how much to order (the order quantity) and when to place an order so that inventory-related costs are minimized. The underlying assumption of these models is that demand is known with certainty and is constant. In addition, we will include models for determining the order size and reorder points (when to place an order) when demand is uncertain.

## Elements of Inventory Management

*Inventory is a stock of items kept on hand to meet demand.*

*Inventory* is defined as a stock of items kept on hand by an organization to use to meet customer demand. Virtually every type of organization maintains some form of inventory. A department stores carries inventories of all the retail items it sells; a nursery has inventories of different plants, trees, and flowers; a rental car agency has inventories of cars; and a major-league baseball team maintains an inventory of players on its minor-league teams. Even a family household will maintain inventories of food, clothing, medical supplies, personal hygiene products, and so on.

### The Role of Inventory

A company or organization keeps stocks of inventory for a variety of important reasons. The most prominent is holding finished goods inventories to meet customer demand for a product, especially in a retail operation. However, customer demand can also be a secretary going to a storage closet to get a printer ribbon or paper, or a carpenter getting a board or nail from a storage shed. A level of inventory is normally maintained that will meet anticipated or expected customer demand. However, because demand is usually not known with certainty, additional amounts of inventory called *safety* or *buffer stocks* are often kept on hand to meet unexpected variations in excess of expected demand.

Additional stocks of inventories are sometimes built up to meet seasonal or cyclical demand. Companies will produce items when demand is low in order to meet high seasonal demand for which their production capacity is insufficient. For example, toy manufacturers produce large inventories during the summer and fall to meet anticipated demand during the Christmas season. Doing so enables them to maintain a relatively smooth production flow throughout the year. They would not normally have the production capacity or logistical support to produce enough to meet all of the Christmas demand during that season. Correspondingly, retailers might find it necessary to keep large stocks of inventory on their shelves to meet peak seasonal demand, such as at Christmas, or for display purposes to attract buyers.



A company will often purchase large amounts of inventory to take advantage of price discounts, as a hedge against anticipated price increases in the future, or because it can get a lower price by purchasing in volume. For example, Wal-Mart Stores have long been known to purchase an entire manufacturer's stock of soap powder or other retail items because it can get a very low price, which it subsequently passes on to its customers. Companies will often purchase large stocks of items when a supplier liquidates in order to get a low price. In some cases, large orders will be made simply because the cost of an order may be very high and it is more cost-effective to have higher inventories than to make a lot of orders.

Many companies find it necessary to maintain in-process inventories at different stages in a manufacturing process to provide independence between operations and to avoid work stoppages or delays. Inventories of raw materials and purchased parts are kept on hand so that the production process will not be delayed as a result of missed or late deliveries or shortages from a supplier. Work-in-process inventories are kept between stages in the manufacturing process so that production can continue smoothly if there are temporary machine breakdowns or other work stoppages. Similarly, a stock of finished parts or products allows customer demand to be met in the event of a work stoppage or problem with the production process.

### Demand

A crucial component and the basic starting point for the management of inventory is customer demand. Inventory exists for the purpose of meeting the demand of customers. Customers can be inside the organization, such as a machine operator waiting for a part or a partially completed product to work on, or external to the organization, such as an individual purchasing groceries or a new stereo. As such, an essential determinant of effective inventory management is an accurate forecast of demand. For this reason the topics of forecasting (chapter 17) and inventory management are directly interrelated.

*Dependent demand items are used internally to produce a final product.*

In general, the demand for items in inventory is classified as dependent or independent. *Dependent demand* items are typically component parts, or materials, used in the process to produce a final product. For example, if an automobile company plans to produce 1,000 new cars, it will need 5,000 wheels and tires (including spares). In this case the demand for wheels is dependent on the production of cars, that is, the demand for one item is a function of demand for another item.

*Independent demand items are final products demanded by an external customer.*

Alternatively, cars are an example of an *independent demand* item. In general, independent demand items are final or finished products that are not a function of, or dependent upon, internal production activity. Independent demand is usually external, and, thus, beyond the direct control of the organization. In this chapter we will focus on the management of inventory for independent demand items.

### Inventory Costs

*Inventory costs include carrying, ordering, and shortage costs.*

There are three basic costs associated with inventory: carrying or holding costs, ordering costs, and shortage costs. *Carrying costs* are the costs of holding items in storage. These vary with the level of inventory and occasionally with the length of time an item is held, i.e., the greater the level of inventory over time, the higher the carrying cost(s). Carrying costs can include the cost of losing the use of funds tied up in inventory; direct storage costs such as rent, heating, cooling, lighting, security, refrigeration, record keeping, and logistics; interest on loans used to purchase inventory; depreciation; obsolescence as markets for products in inventory diminish; product deterioration and spoilage; breakage; taxes; and pilferage.

Carrying costs are normally specified in one of two ways. The most general form is to assign total carrying costs, determined by summing all the individual costs mentioned previously, on a per unit basis per time period, such as a month or year. In this form, carrying costs would commonly be expressed as a per unit dollar amount on an annual basis, for example, $10 per year. Alternatively, carrying costs are sometimes expressed as a percentage of the value of an item or as a percentage of average inventory value. It is generally estimated that carrying costs range from 10% to 40% of the value of a manufactured item.

*Ordering costs* are the costs associated with replenishing the stock of inventory being held. These are normally expressed as a dollar amount per order and are independent of the order size. Thus, ordering costs vary with the number of orders made (i.e., as the number of orders increases, the ordering cost increases). Costs incurred each time an order is made can include requisition costs, purchase orders, transportation and shipping, receiving, inspection, handling and placing in storage, and accounting and auditing.

Ordering costs generally react inversely to carrying costs. As the size of orders increases, fewer orders are required, thus reducing annual ordering costs. However, ordering larger amounts results in higher inventory levels and higher carrying costs. In general, as the order size increases, annual ordering costs decrease and annual carrying costs increase.

*Shortage costs*, also referred to as *stockout costs*, occur when customer demand cannot be met because of insufficient inventory on hand. If these shortages result in a permanent loss of sales for items demanded but not provided, shortage costs include the loss of profits. Shortages can also cause customer dissatisfaction and a loss of goodwill that can result in a permanent loss of customers and future sales. In some instances the inability to meet customer demand or lateness in meeting demand results in specified penalties in the form of price discounts or rebates. When demand is internal, a shortage can cause work stoppages in the production process and create delays, resulting in downtime costs and the cost of lost production (including indirect and direct production costs).

Costs resulting from immediate or future lost sales because demand could not be met are more difficult to determine than carrying or ordering costs. As a result, shortage costs are frequently subjective estimates and many times no more than educated guesses.

Shortages occur because it is costly to carry inventory in stock. As a result, shortage costs have an inverse relationship to carrying costs; as the amount of inventory on hand increases, the carrying cost increases while shortage costs decrease.

*The purpose of inventory management is to determine how much and when to order.*

The objective of inventory management is to employ an inventory control system that will indicate how much should be ordered and when orders should take place in order to minimize the sum of the three inventory costs described earlier.

## Inventory Control Systems

An inventory system is a structure for controlling the level of inventory by determining how much to order (the level of replenishment) and when to order. There are two basic types of inventory systems: a *continuous (or fixed-order quantity) system* and a *periodic (or fixed-time period) system*. The primary difference between the two systems is that in a continuous system an order is placed for the same constant amount whenever the inventory on hand decreases to a certain level, whereas in a periodic system an order is placed for a variable amount after an established passage of time.



### Continuous Inventory Systems

*In a continuous inventory system a constant amount is ordered when inventory declines to a predetermined level.*

In a *continuous inventory system*, alternatively referred to as a *perpetual system*, and a *fixed-order quantity system*, a continual record of the inventory level for every item is maintained. Whenever the inventory on hand decreases to a predetermined level, referred to as the *reorder point*, a new order is placed to replenish the stock of inventory. The order that is placed is for a "fixed" amount that minimizes the total inventory carrying, ordering, and shortage costs. This fixed-order amount is called the *economic order quantity*; its determination will be discussed in greater detail in a later section.

A positive feature of a continuous system is that the inventory level is closely and continuously monitored so that management always knows the inventory status. This is especially advantageous for critical inventory items such as replacement parts or raw materials and supplies. However, the cost of maintaining a continual record of the amount of inventory on hand can also be a disadvantage of this type of system.

A simple example of a continuous inventory system is a ledger-style checkbook that many of us use on a daily basis. Our checkbook comes with 300 checks; after the 200th check has been used (and there are 100 left), there is an order form for a new batch of checks that has been inserted by the printer. This form, when turned in at the bank, initiates an order for a new batch of 300 checks from the printer. Many office inventory systems use "reorder" cards that are placed within stacks of stationery or at the bottom of a case of pens or paper clips to signal when a new order should be placed. If you look behind the items on a hanging rack in a K-Mart store, there will be a card indicating it is time to place an order for this item for an amount indicated on the card.

A more sophisticated example of a continuous inventory system is a computerized checkout system with a laser scanner used by many supermarkets and retail stores. In this system a laser scanner reads the Universal Product Code (UPC), or bar code, off of the product package, and the transaction is instantly recorded and the inventory level updated. Such a system is not only quick and accurate, but it also provides management with continuously updated information on the status of inventory levels. Although not as publicly visible as supermarket systems, many manufacturing companies, suppliers, and distributors also use bar code systems and handheld laser scanners to inventory materials, supplies, equipment, in-process parts, and finished goods.

Because continuous inventory systems are much more common than periodic systems, models that determine fixed-order quantities and the time to order will receive most of our attention in this chapter.

### Periodic Inventory Systems

*In a periodic inventory system an order is placed for a variable amount after a fixed passage of time.*

In a *periodic inventory system*, also referred to as a *fixed-time period system* and a *periodic review system*, the inventory on hand is counted at specific time intervals, for example, every week or at the end of each month. After the amount of inventory in stock is determined, an order is placed for an amount that will bring inventory back up to a desired level. In this system the inventory level is not monitored at all during the time interval between orders, so it has the advantage of requiring little or no record keeping. However, it also has the disadvantage of less direct control. This typically results in larger inventory levels for a periodic inventory system than in a continuous system to guard against unexpected stockouts early in the fixed period. Such a system also requires that a new order quantity be determined each time a periodic order is made.

An example of a periodic inventory system is often found at the bookstore at a college or university. Textbooks are normally ordered according to a periodic system wherein a count of textbooks in stock (for every course) is made after the first few weeks or month during the semester or quarter. An order for new textbooks for the next semester is then made according to estimated course enrollments for the next term (i.e., demand) and the amount remaining in stock. Smaller retail stores, drugstores, grocery stores, and offices often use periodic systems; the stock level is checked every week or month, often by a vendor, to see how much (if anything) should be ordered.

## Time Out for Ford Harris

The earliest published derivation of the classic economic lot size model is credited to Ford Harris of Westinghouse Corporation in 1915. His equation determined a minimum sum of inventory costs and setup costs, given demand that was known and constant and a rate of production that was assumed to be higher than demand.

# Economic Order Quantity Models

*EOQ is a continuous inventory system.*

You will recall that in a continuous or fixed-order quantity system when inventory reaches a specific level, referred to as the *reorder point*, a fixed amount is ordered. The most widely used and traditional means for determining how much to order in a continuous system is the *economic order quantity* (EOQ) model, also referred to as the economic lot size model.

The function of the EOQ model is to determine the optimal order size that minimizes total inventory costs. There are several variations of the EOQ model, depending on the assumptions made about the inventory system. In this and following sections we will describe three model versions: the basic EOQ model, the EOQ model with noninstantaneous receipt, and the EOQ model with shortages.

# The Basic EOQ Model

*EOQ is the optimal order quantity that will minimize total inventory costs.*

The simplest form of the economic order quantity model on which all other model versions are based is called the basic EOQ model. It is essentially a single formula for determining the optimal order size that minimizes the sum of carrying costs and ordering costs. The model formula is derived under a set of simplifying and restrictive assumptions, as follows:

*Assumptions of the EOQ model include constant demand, no shortages, constant lead time, and instantaneous order receipt.*

- Demand is known with certainty and is relatively constant over time.
- No shortages are allowed.
- Lead time for the receipt of orders is constant.
- The order quantity is received all at once.

The graph in Figure 18.1 reflects these basic model assumptions.

**Figure 18.1**
The inventory order cycle

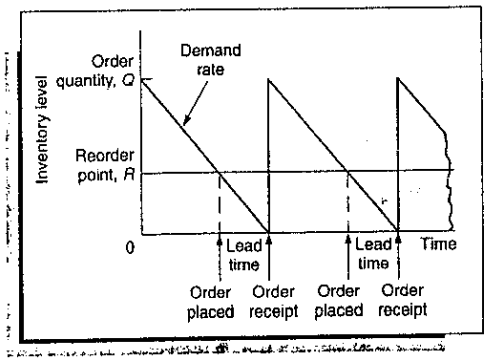





Figure 18.1 describes the continuous inventory order cycle system inherent in the EOQ model. An order quantity, $Q$, is received and is used up over time at a constant rate. When the inventory level decreases to the reorder point, $R$, a new order is placed and a period of time, referred to as the lead time, is required for delivery. The order is received all at once just at the moment when demand depletes the entire stock of inventory (and the inventory level reaches zero), thus allowing no shortages. This cycle is continuously repeated for the same order quantity, reorder point, and lead time.

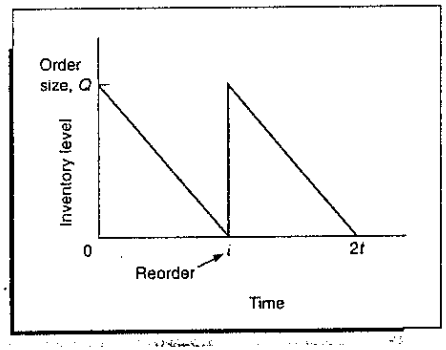
As we mentioned earlier, $Q$ is the order size that minimizes the sum of carrying costs and holding costs. These two costs react inversely to each other in response to an increase in the order size. As the order size increases, fewer orders are required, causing the ordering cost to decline, whereas the average amount of inventory on hand will increase, resulting in an increase in carrying costs. Thus, in effect, the optimal order quantity represents a compromise between these two conflicting costs.

## Carrying Cost

Carrying cost is usually expressed on a per unit basis for some period of time (although it is sometimes given as a percentage of average inventory). Traditionally, the carrying cost is referred to on an annual basis (i.e., per year).

The total carrying cost is determined by the amount of inventory on hand during the year. The amount of inventory available during the year is illustrated in Figure 18.2.

**Figure 18.2**
Inventory usage




In Figure 18.2, $Q$ represents the size of the order needed to replenish inventory, which is what the manager wants to determine. The line connecting $Q$ to time, $t$, in our graph represents the rate at which inventory is depleted, *demand*, during the time period, $t$. Demand is assumed to be *known with certainty* and is thus constant, which explains why the line representing demand is straight. Also, notice that inventory never goes below zero; shortages do not exist. In addition, when the inventory level does reach zero, it is assumed that an order arrives immediately after an infinitely small passage of time, a condition referred to as *instantaneous receipt*. This is a simplifying assumption that we will maintain for the moment.

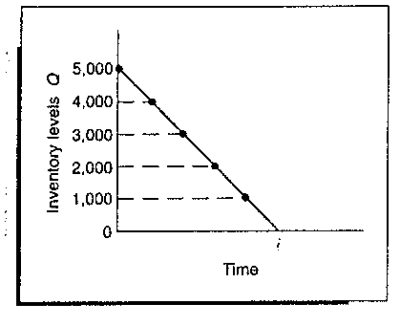
Referring to Figure 18.2, we can see that the amount of inventory is $Q$, the size of the order, for an infinitely small period of time because $Q$ is always being depleted by demand. Similarly, the amount of inventory is zero for an infinitely small period of time because the only time there is no inventory is at the specific time $t$. Thus, the amount of inventory available is somewhere between these two extremes. A logical deduction is that the amount of inventory available is the *average inventory* level, defined as

$$\text{average inventory} = \frac{Q}{2}$$

In order to verify this relationship, specify any number of points—values of $Q$—over the entire time period, $t$, and divide by the number of points. For example, if $Q = 5{,}000$, the six points designated from 5,000 to zero, as shown in Figure 18.3, are summed and divided by 6.

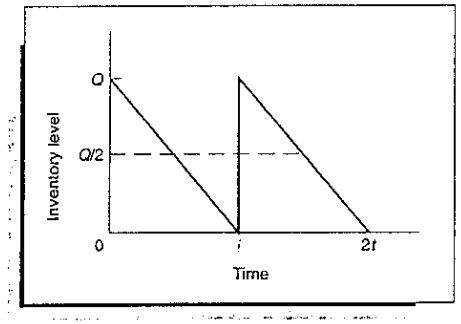
$$\text{average inventory} = \frac{5{,}000 + 4{,}000 + 3{,}000 + 2{,}000 + 1{,}000 + 0}{6}$$
$$= 2{,}500$$

**Figure 18.3**
Levels of $Q$




Alternatively, sum just the two extreme points (which also encompass the range of time, $t$) and divide by 2. This also equals 2,500. This computation is the same, in principle, as adding $Q$ and 0 and dividing by 2, which equals $Q/2$. This relationship for average inventory is maintained regardless of the size of the order, $Q$, or the frequency of orders (i.e., the time period, $t$). Thus, the average inventory on an *annual basis* is also $Q/2$, as shown in Figure 18.4.

**Figure 18.4**
Average inventory




Now that we know that the amount of inventory available *on an annual basis* is the average inventory, $Q/2$, we can determine the total annual carrying cost by multiplying the average number of units in inventory by the carrying cost per unit per year, $C_c$,

$$\text{annual carrying cost} = C_c \frac{Q}{2}$$



**Ordering Cost**

The total annual ordering cost is computed by multiplying the cost per order, designated as $C_o$, by the number of orders per year. Because annual demand is assumed to be known and constant, the number of orders will be $D/Q$, where $Q$ is the order size:

$$\text{annual ordering cost} = C_o \frac{D}{Q}$$

The only variable in this equation is $Q$; both $C_o$ and $D$ are constant parameters. In other words, demand is known with certainty. Thus, the relative magnitude of the ordering cost is dependent upon the order size.

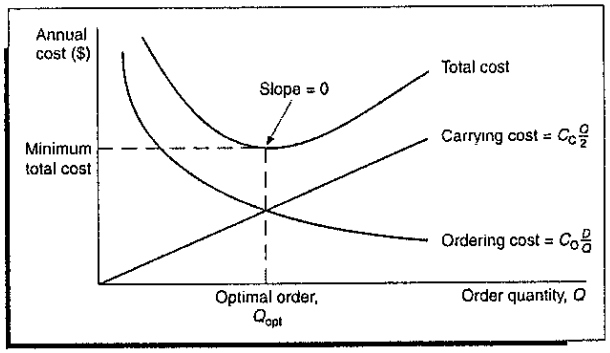
**Total Inventory Cost**

The total annual inventory cost is simply the sum of the ordering and carrying costs.

$$TC = C_o \frac{D}{Q} + C_c \frac{Q}{2}$$

These cost functions are shown in Figure 18.5. Notice the inverse relationship between ordering cost and carrying cost, resulting in a convex total cost curve.

**Figure 18.5**
The EOQ cost model




Observe the general upward trend of the total carrying cost curve. As the order size $Q$ (shown on the horizontal axis) increases, the total carrying cost (shown on the vertical axis) increases. This is logical because larger orders will result in more units carried in inventory. Next, observe the ordering cost curve in Figure 18.5. As the order size, $Q$, increases, the ordering cost *decreases* (just the opposite of what occurred with the carrying cost). This is logical because an increase in the size of the orders will result in fewer orders being placed each year. Because one cost increases as the other decreases, the result of summing the two costs is a convex total cost curve.

*Optimal Q corresponds to the lowest point on the total cost curve.*

The optimal order quantity occurs at the point in Figure 18.5 where the total cost curve is at a minimum, which also coincides exactly with the point where the ordering cost curve intersects with the carrying cost curve. This enables us to determine the optimal value of $Q$ by equating the two cost functions and solving for $Q$ as follows.

$$C_o \frac{D}{Q} = C_c \frac{Q}{2}$$

$$Q^2 = \frac{2C_oD}{C_c}$$

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c}}$$

Alternatively, the optimal value of Q can be determined by differentiating the total cost curve with respect to Q, setting the resulting function equal to zero (the slope at the minimum point on the total cost curve) and solving for Q, as follows.

$$TC = C_o \frac{D}{Q} + C_c \frac{Q}{2}$$

$$\frac{\delta TC}{\delta Q} = -\frac{C_oD}{Q^2} + \frac{C_c}{2}$$

$$0 = -\frac{C_oD}{Q^2} + \frac{C_c}{2}$$

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c}}$$

The total minimum cost is determined by substituting the value for the optimal order size, $Q_{opt}$, into the total cost equation.

$$TC_{min} = \frac{C_oD}{Q_{opt}} + C_c \frac{Q_{opt}}{2}$$

We will use the following example to demonstrate how the optimal value of Q is computed. The I-75 Carpet Discount Store in North Georgia stocks carpet in its warehouse and sells it through an adjoining showroom. The store keeps several brands and styles of carpet in stock; however, its biggest seller is Super Shag carpet. The store wants to determine the optimal order size and total inventory cost for this brand of carpet given an estimated annual demand of 10,000 yards of carpet, an annual carrying cost of $0.75 per yard, and an ordering cost of $150. The store would also like to know the number of orders that will be made annually and the time between orders (i.e., the order cycle) given that the store is open every day except Sunday, Thanksgiving Day, and Christmas Day (which is not on a Sunday).

Summarizing the model parameters,

$C_c$ = $0.75
$C_o$ = $150
$D$ = 10,000 yd

The optimal order size is computed as follows.

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c}}$$

$$= \sqrt{\frac{2(150)(10{,}000)}{(0.75)}}$$

$$Q_{opt} = 2{,}000 \text{ yd}$$



The total annual inventory cost is determined by substituting $Q_{opt}$ into the total cost formula as follows.

$$TC_{min} = C_o \frac{D}{Q_{opt}} + C_c \frac{Q_{opt}}{2}$$

$$= (150) \frac{10{,}000}{2{,}000} + (0.75) \frac{(2{,}000)}{2}$$

$$= \$750 + 750$$

$$TC_{min} = \$1{,}500$$

The number of orders per year is computed as follows:

$$\text{number of orders per year} = \frac{D}{Q_{opt}} = \frac{10{,}000}{2{,}000} = 5$$

Given that the store is open 311 days annually (365 days minus 52 Sundays, plus Thanksgiving and Christmas) the order cycle is determined as follows:

$$\text{order cycle time} = \frac{311 \text{ days}}{D/Q_{opt}} = \frac{311}{5} = 62.2 \text{ store days}$$

*The EOQ model is robust; because Q is a square root, errors in the estimation of D, $C_c$, and $C_o$ are dampened.*

It should be noted that the optimal order quantity determined in this example, and in general, is an approximate value because it is based on estimates of carrying and ordering costs as well as uncertain demand (although all of these parameters are treated as known, certain values in the EOQ model). Thus, in practice it is acceptable to round the Q values off to the nearest whole number. The precision of a decimal place generally is neither necessary nor appropriate. In addition, because the optimal order quantity is computed from a square root, errors or variations in the cost parameters and demand tend to be dampened. For instance, if the order cost had actually been a third higher, or $200, the resulting optimal order size would have only varied by a little under 10% (i.e., 2,190 yards instead of 2,000 yards). In addition, variations in both inventory costs will tend to offset each other because they have an inverse relationship. As a result, the EOQ model is relatively robust, or resilient to errors in the cost estimates and demand, which has tended to enhance its popularity.

## EOQ Analysis over Time

One aspect of inventory analysis that can be confusing is the time frame encompassed by the analysis. Therefore, we will digress for just a moment to discuss this aspect of EOQ analysis.

Recall that previously we developed the EOQ model "regardless of order size, Q, and time, *t*." Now we will verify this condition. We will do so by developing our EOQ model on a *monthly basis*. First, demand is equal to 833.3 yards per month (which we determined by dividing the annual demand of 10,000 yards by 12 months). Next, by dividing the annual carrying cost, $C_c$, of $0.75 by 12, we get the monthly (per unit) carrying cost: $C_c$ = $0.0625. (The ordering cost of $150 is not related to time.) We thus have the values

$D$ = 833.3 yd per month
$C_c$ = $0.0625 per yd per month
$C_o$ = $150 per order

which we can substitute into our EOQ formula:

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_r}}$$

$$= \sqrt{\frac{2(150)(833.3)}{(0.0625)}} = 2{,}000 \text{ yd}$$

This is the same optimal order size that we determined on an annual basis. Now we will compute total monthly inventory cost:

$$\text{total monthly inventory cost} = C_r\frac{Q_{opt}}{2} + C_o\frac{D}{Q_{opt}}$$

$$= (\$0.0625)\frac{(2{,}000)}{2} + (\$150)\frac{(833.3)}{(2{,}000)}$$

$$= \$125 \text{ per month}$$

In order to convert this monthly total cost to an annual cost, we multiply it by 12 (months):

$$\text{total annual inventory cost} = (\$125)(12) = \$1{,}500$$

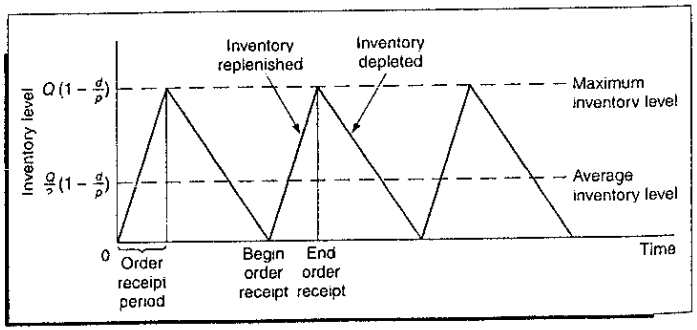
This brief example demonstrates that regardless of the time period encompassed by EOQ analysis, the economic order quantity ($Q_{opt}$) is the same.

## The EOQ Model with Noninstantaneous Receipt

*The noninstantaneous receipt model relaxes the assumption that Q is received all at once.*

A variation of the basic EOQ model is achieved when the assumption that orders are received all at once is relaxed. This version of the EOQ model is known as the *noninstantaneous receipt model*, also referred to as the *gradual usage* and *production lot size model*. In this EOQ variation the order quantity is received gradually over time and the inventory level is depleted at the same time it is being replenished. This is a situation most commonly found when the inventory user is also the producer as, for example, in a manufacturing operation where a part is produced to use in a larger assembly. This situation can also occur when orders are delivered gradually over time or the retailer and producer of a product are one in the same. The noninstantaneous receipt model is illustrated graphically in Figure 18.6, which highlights the difference between this variation and the basic EOQ model.

**Figure 18.6**
The EOQ model with noninstantaneous order receipt






The ordering cost component of the basic EOQ model does not change as a result of the gradual replenishment of the inventory level, since it is dependent only on the number of annual orders. However, the carrying cost component is not the same for this model variation because average inventory is different. In the basic EOQ model, average inventory was half the maximum inventory level, or $Q/2$, but in this variation the maximum inventory level is not simply $Q$; it is an amount somewhat lower than $Q$ adjusted for the fact that the order quantity is depleted during the order receipt period.

In order to determine the average inventory level we define the following parameters unique to this model.

$p$ = daily rate at which the order is received over time, also known as the *production rate*
$d$ = the daily rate at which inventory is demanded

The demand rate cannot exceed the production rate because we are still assuming that no shortages are possible, and if $d = p$, then there is no order size because items are used as fast as they are produced. Thus, for this model the production rate must exceed the demand rate, or $p > d$.

Observing Figure 18.6, the time required to receive an order is the order quantity divided by the rate at which the order is received, or $Q/p$. For example, if the order size is 100 units and the production rate, $p$, is 20 units per day, the order will be received in five days. The amount of inventory that will be depleted or used up during this time period is determined by multiplying by the demand rate, or $(Q/p)d$. For example, if it takes five days to receive the order and during this time inventory is depleted at the rate of 2 units per day, then a total of 10 units is used. As a result, the maximum amount of inventory that is on hand is the order size minus the amount depleted during the receipt period, computed as follows and shown earlier in Figure 18.6:

$$\text{maximum inventory level} = Q - \frac{Q}{p}d$$

$$= Q\left(1 - \frac{d}{p}\right)$$

Because this is the maximum inventory level, the average inventory level is determined by dividing this amount by 2, as follows:

$$\text{average inventory level} = \frac{1}{2}\left[Q\left(1 - \frac{d}{p}\right)\right]$$

$$= \frac{Q}{2}\left(1 - \frac{d}{p}\right)$$

The total carrying cost using this function for average inventory is

$$\text{total carrying cost} = C_r\frac{Q}{2}\left(1 - \frac{d}{p}\right)$$

Thus, the total annual inventory cost is determined according to the following formula.

$$TC = C_o\frac{D}{Q} + C_r\frac{Q}{2}\left(1 - \frac{d}{p}\right)$$

The total inventory cost is a function of two other costs, just as in our previous EOQ model. Thus, the minimum inventory cost occurs when the total cost curve is lowest and where the carrying cost curve and ordering cost curve intersect (see Figure 18.5). Therefore, to find optimal $Q_{opt}$, we equate total carrying cost with total ordering cost.

$$C_c \frac{Q}{2}\left(1 - \frac{d}{p}\right) = C_o \frac{D}{Q}$$

$$C_c \frac{Q^2}{2}\left(1 - \frac{d}{p}\right) = C_o D$$

$$Q_{opt} = \sqrt{\frac{2C_o D}{C_c(1 - d/p)}}$$

For our previous example we will now assume that the I-75 Carpet Discount Store has its own manufacturing facility in which it produces Super Shag carpet. We will further assume that the ordering cost, $C_o$, is the cost of setting up the production process to make Super Shag carpet. Recall that $C_c$ = \$0.75 per yard and $D$ = 10,000 yards per year. The manufacturing facility operates the same days the store is open (i.e., 311 days) and produces 150 yards of the carpet per day. The optimal order size, total inventory cost, the length of time to receive an order, the number of orders per year, and the maximum inventory level are computed as follows.

$C_o$ = \$150
$C_c$ = \$0.75 per unit
$D$ = 10,000 yd
$d = \frac{10,000}{311} = 32.2$ yd per day
$p$ = 150 yd per day

The optimal order size is determined as follows.

$$Q_{opt} = \sqrt{\frac{2C_o D}{C_c\left(1 - \frac{d}{p}\right)}}$$

$$= \sqrt{\frac{2(150)(10,000)}{0.75\left(1 - \frac{32.2}{150}\right)}}$$

$Q_{opt}$ = 2,256.8 yd

This value is substituted into the following formula to determine total minimum annual inventory cost.

$$TC_{min} = C_o \frac{D}{Q} + C_c \frac{Q}{2}\left(1 - \frac{d}{p}\right)$$

$$= (150)\frac{(10,000)}{(2,256.8)} + (0.75)\frac{(2,256.8)}{2}\left(1 - \frac{32.2}{150}\right)$$

= \$1,329

The length of time to receive an order for this type of manufacturing operation is commonly called the length of the *production run*. It is computed as follows:

$$\text{production run length} = \frac{Q}{p} = \frac{2,256.8}{150} = 15.05 \text{ days}$$

The number of orders per year is actually the number of production runs that will be made, computed as follows:



$$\text{number of production runs} = \frac{D}{Q}$$

$$= \frac{10,000}{2,256.8}$$

= 4.43 runs

Finally, the maximum inventory level is computed as follows:

$$\text{maximum inventory level} = Q\left(1 - \frac{d}{p}\right)$$

$$= 2,256.8\left(1 - \frac{32.2}{150}\right)$$

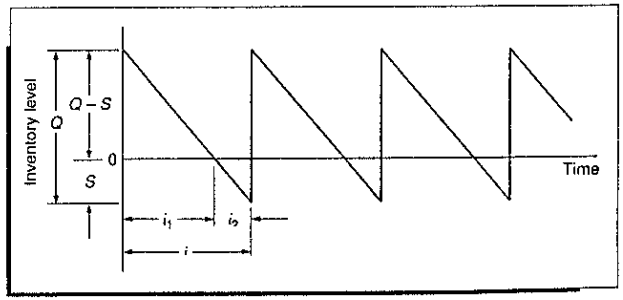
= 1,772 yd

## The EOQ Model with Shortages

*The EOQ model with shortages relaxes the assumption that shortages cannot exist.*

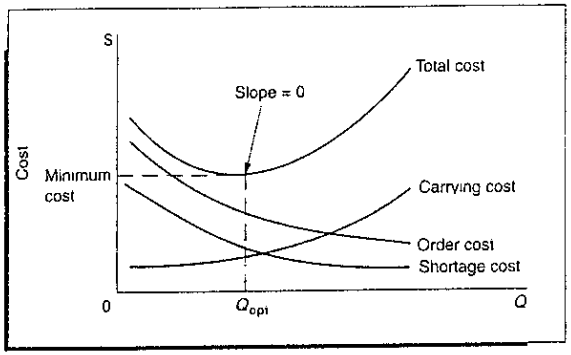
One of the assumptions of our basic EOQ model is that shortages and back ordering are not allowed. The third model variation that we will describe, the EOQ model with shortages, relaxes this assumption. However, it will be assumed that all demand not met because of inventory shortage can be back ordered and delivered to the customer later. Thus, all demand is eventually met. The EOQ model with shortages is illustrated in Figure 18.7.

**Figure 18.7**
The EOQ model with shortages




Because backordered demand, or shortages, $S$, are filled when inventory is replenished, the maximum inventory level does not reach $Q$, but instead a level equal to $Q - S$. It can be seen from Figure 18.7 that the amount of inventory on hand ($Q - S$) decreases as the amount of the shortage increases, and vice versa. As such, the cost associated with shortages, which we described earlier in this chapter as primarily the cost of lost sales and lost customer goodwill, has an inverse relationship to carrying costs. As the order size, $Q$, increases, the carrying cost increases and the shortage cost declines. This relationship between carrying and shortage cost as well as ordering cost is shown in Figure 18.8.

**Figure 18.8**
Cost model with shortages




We will forgo the lengthy derivation of the individual cost components of the EOQ model with shortages, which requires the application of plane geometry to the graph in Figure 18.8. The individual cost functions are provided as follows, where $S$ equals the shortage level and $C_s$ equals the annual per unit cost of shortages.

$$\text{total shortage costs} = C_s \frac{S^2}{2Q}$$

$$\text{total carrying cost} = C_c \frac{(Q - S)^2}{2Q}$$

$$\text{total ordering cost} = C_o \frac{D}{Q}$$

Combining these individual cost components results in the total inventory cost formula:

$$TC = C_s \frac{S^2}{2Q} + C_c \frac{(Q - S)^2}{2Q} + C_o \frac{D}{Q}$$

You will notice from Figure 18.8 that the three cost component curves do not intersect at a common point as was the case in the basic EOQ model. As a result, the only way to determine the optimal order size *and the optimal shortage level, S,* is to differentiate the total cost function with respect to $Q$ and $S$, set the two resulting equations equal to zero, and solve them simultaneously. Doing so results in the following formulas for the optimal order quantity and shortage level.

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c}\left(\frac{C_s + C_c}{C_s}\right)}$$

$$S_{opt} = Q_{opt}\left(\frac{C_c}{C_c + C_s}\right)$$

For example, we will now assume that the I-75 Carpet Discount Store allows shortages and the shortage cost, $C_s$, is $2 per yard per year. All other costs and demand remain the same ($C_c$ = $0.75, $C_o$ = $150, and $D$ = 10,000 yd). The optimal order size and shortage level, and total minimum annual inventory cost are computed as follows.

$C_o$ = $150
$C_c$ = $0.75 per yard
$C_s$ = $2 per yard
$D$ = 10,000 yd



$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c}\left(\frac{C_s + C_c}{C_c}\right)}$$

$$= \sqrt{\frac{2(150)(10{,}000)}{0.75}\left(\frac{2 + 0.75}{2}\right)}$$

$$= 2{,}345.2 \text{ yd}$$

$$S_{opt} = Q_{opt}\left(\frac{C_c}{C_c + C_s}\right)$$

$$= 2{,}345.2\left(\frac{0.75}{2 + 0.75}\right)$$

$$= 639.6 \text{ yd}$$

$$TC_{min} = \frac{C_sS^2}{2Q} + \frac{C_c(Q - S)^2}{2Q} + C_o\frac{D}{Q}$$

$$= \frac{(2)(639.6)^2}{2(2{,}345.2)} + \frac{(0.75)(1{,}705.6)^2}{2(2{,}345.2)} + \frac{(150)(10{,}000)}{2{,}345.2}$$

$$= \$174.44 + 465.16 + 639.60$$

$$= \$1{,}279.20$$

# 7056ENG

Resource Planning and Management

# Example Questions

Dr Rodney Stewart

# Activity-on-Arrow Networks

Draw the activity-on-arrow network diagram for the following projects, calculate the earliest and latest starting and finishing times for all activities, and hence calculate the total float and free float for each activity.

## Question 1

***Project A***

| Activity | Duration | IFA |
|---|---|---|
| A | 22 | D & J |
| B | 10 | C & F |
| C | 13 | D & J |
| D | 8 | ------- |
| E | 15 | C, F & G |
| F | 17 | H, I & K |
| G | 15 | H, I & K |
| H | 6 | D & J |
| I | 11 | J |
| J | 12 | ------- |
| K | 20 | -------- |

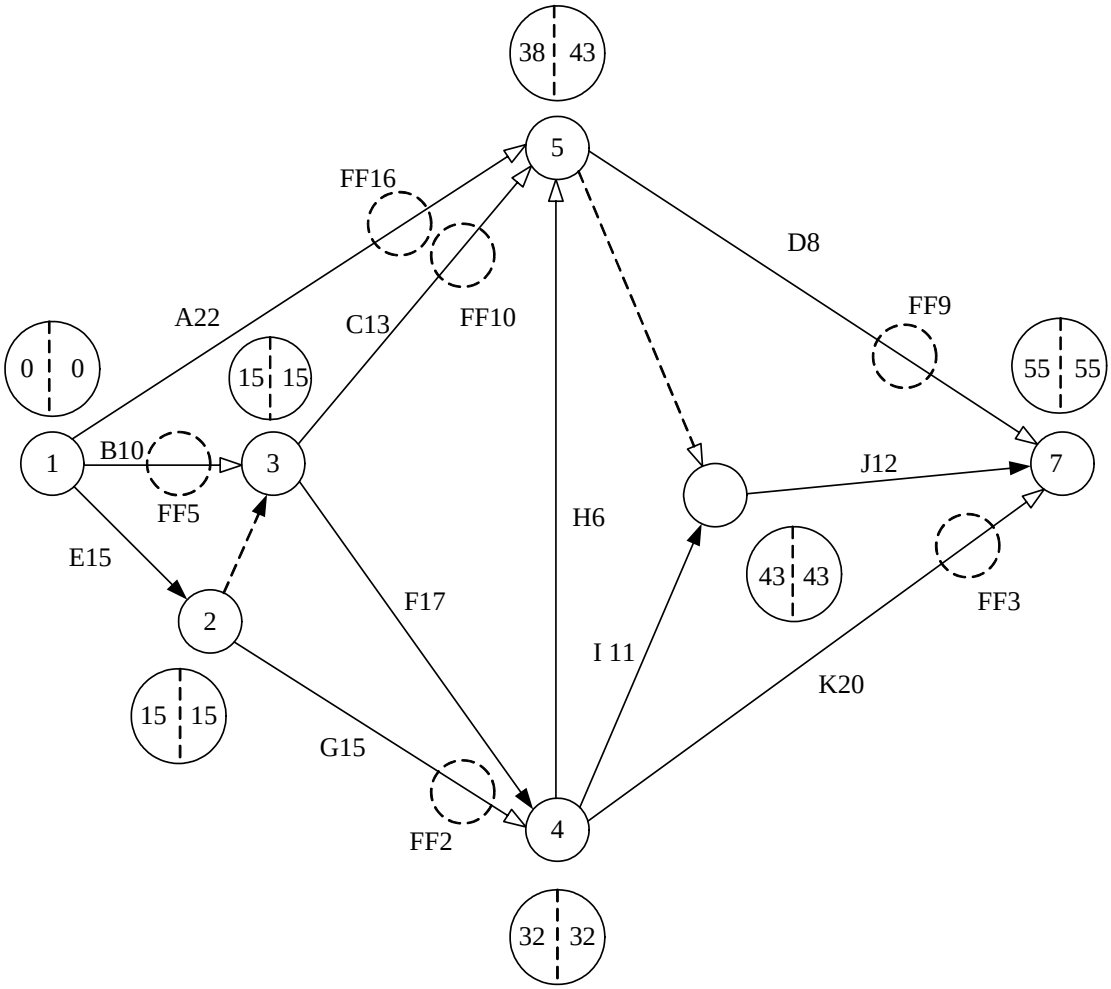
## Question 2

***Project B***

| Activity | Duration (days) |
|---|---|
| 1-2 | 5 |
| 1-3 | 10 |
| 1-4 | 12 |
| 2-4 | Dummy |
| 2-5 | 14 |
| 3-4 | 6 |
| 3-6 | 13 |
| 4-5 | 7 |
| 4-7 | 11 |
| 5-7 | 17 |
| 5-9 | 9 |
| 6-7 | Dummy |
| 6-8 | 8 |
| 7-8 | 5 |
| 7-9 | 13 |
| 7-10 | 8 |
| 8-10 | 14 |
| 9-10 | 6 |

# Activity-on-Arrow Networks - Solutions

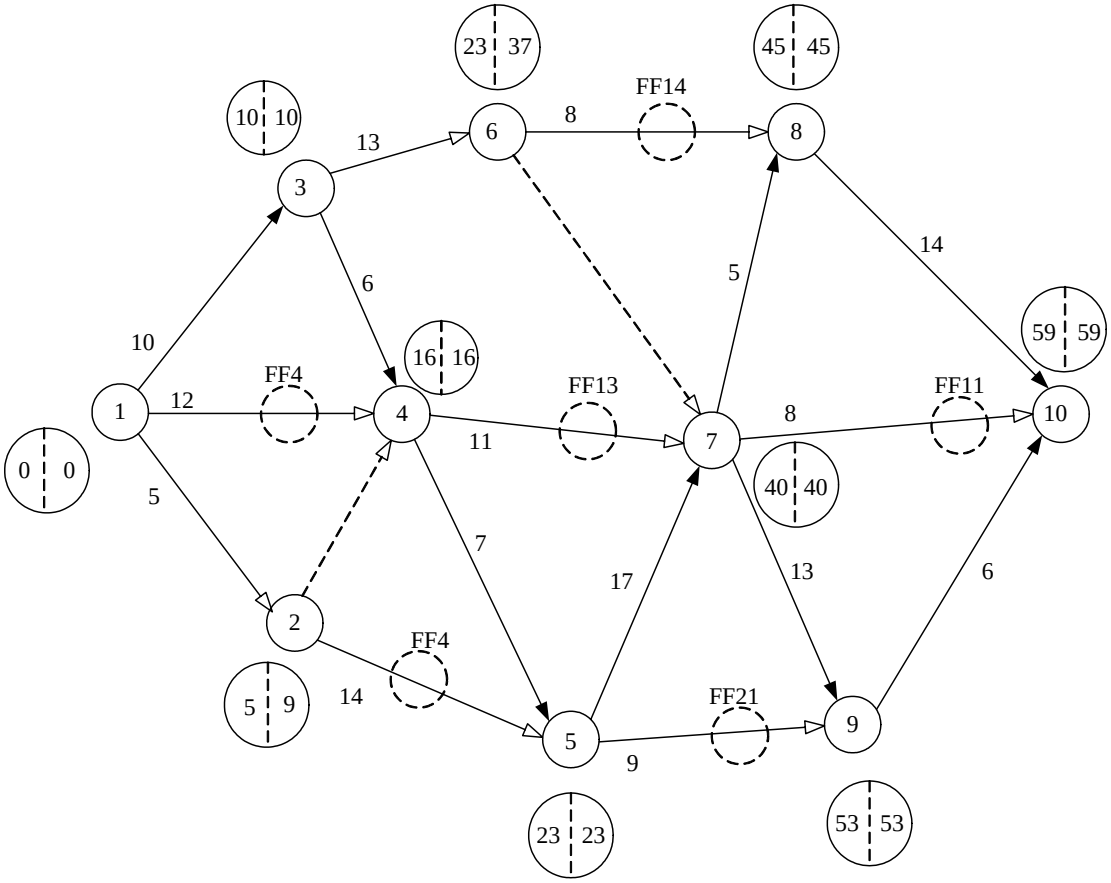
## Question 1 Solution




**Arrow Notation**

| Activity | Total Float | Free Float | Interfering Float | Status |
|---|---|---|---|---|
| **A** | 21 | 16 | 5 | |
| **B** | 5 | 5 | 0 | |
| **C** | 15 | 10 | 5 | |
| **D** | 9 | 9 | 0 | |
| **E** | 0 | 0 | 0 | Critical |
| **F** | 0 | 0 | 0 | Critical |
| **G** | 2 | 2 | 0 | |
| **H** | 5 | 0 | 5 | |
| **I** | 0 | 0 | 0 | Critical |
| **J** | 0 | 0 | 0 | Critical |
| **K** | 3 | 3 | 0 | |

## Question 2 Solution




| Activity | | Duration | EST | EFT | LST | LFT | TF | FF | Status |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 5 | 0 | 5 | 0 | 5 | 4 | 0 | |
| 1 | 3 | 10 | 0 | 10 | 0 | 10 | 0 | 0 | Critical |
| 1 | 4 | 12 | 0 | 12 | 0 | 12 | 4 | 4 | |
| 2 | 4 | 0 | 5 | 5 | 9 | 9 | 11 | 11 | |
| 2 | 5 | 14 | 5 | 19 | 9 | 23 | 4 | 4 | |
| 3 | 4 | 6 | 10 | 16 | 10 | 16 | 0 | 0 | Critical |
| 3 | 6 | 13 | 10 | 23 | 10 | 23 | 14 | 0 | |
| 4 | 5 | 7 | 16 | 23 | 16 | 23 | 0 | 0 | Critical |
| 4 | 7 | 11 | 16 | 27 | 16 | 27 | 13 | 13 | |
| 5 | 7 | 17 | 23 | 40 | 23 | 40 | 0 | 0 | Critical |
| 5 | 9 | 9 | 23 | 32 | 23 | 32 | 21 | 21 | |
| 6 | 7 | 0 | 23 | 23 | 37 | 37 | 17 | 17 | |
| 6 | 8 | 8 | 23 | 31 | 37 | 45 | 14 | 14 | |
| 7 | 8 | 5 | 40 | 45 | 40 | 45 | 0 | 0 | Critical |
| 7 | 9 | 13 | 40 | 53 | 40 | 53 | 0 | 0 | Critical |
| 7 | 10 | 8 | 40 | 48 | 40 | 48 | 11 | 11 | |
| 8 | 10 | 14 | 45 | 59 | 45 | 59 | 0 | 0 | Critical |
| 9 | 10 | 6 | 53 | 59 | 53 | 59 | 0 | 0 | Critical |

# PDM Networks and Resource Levelling

## Question 1

Draw the PDM network represented by the following activities and then analyse it fully? Show the critical path?

| **ID** | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **IPA** | D | D | - | C | K | D | A | D | H | E | - | D | J,F,G,L,B | M,I |
| **Duration** | 3 | 16 | 1 | 4 | 12 | 3 | 26 | 4 | 2 | 10 | 2 | 6 | 3 | 3 |

## Question 2

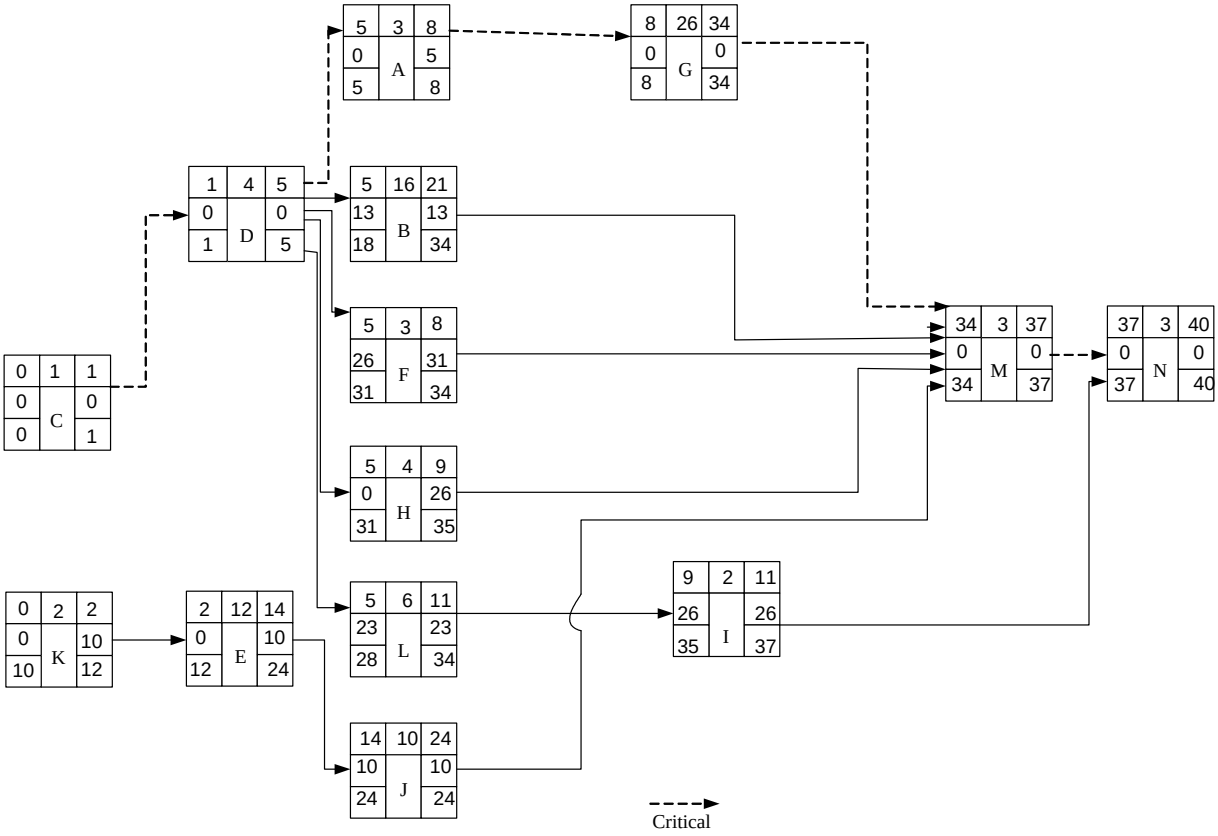
Draw the PDM network diagram for the following project, calculate the earliest and latest starting and finishing times for all activities, and hence calculate the total float, free float for each activity.

| **Activity** | **IPA** | **Duration (WEEKS)** | **WORKERS REQUIRED PER WEEK** | **EQUIPMENT REQUIRED (hrs/WEEK)** |
|---|---|---|---|---|
| **H** | **----** | **10** | **5** | **8** |
| **I** | **H** | **8** | **4** | **2** |
| **J** | **H** | **6** | **8** | **6** |
| **K** | **J** | **4** | **2** | **1** |
| **L** | **J** | **2** | **6** | **2** |
| **M** | **J** | **4** | **3** | **2** |
| **N** | **I** | **4** | **2** | **0** |
| **O** | **I** | **5** | **5** | **0** |
| **P** | **I, J** | **5** | **6** | **6** |
| **Q** | **L** | **5** | **2** | **0** |
| **R** | **M** | **5** | **0** | **4** |
| **S** | **N** | **3** | **0** | **4** |
| **T** | **Q** | **3** | **0** | **0** |
| **U** | **O, S** | **1** | **9** | **8** |
| **V** | **K, R** | **5** | **14** | **8** |
| **W** | **U** | **2** | **6** | **8** |
| **X** | **V** | **3** | **6** | **8** |
| **Y** | **P,W,X,T** | **8** | **14** | **8** |
| **Z** | **Y** | **6** | **5** | **8** |

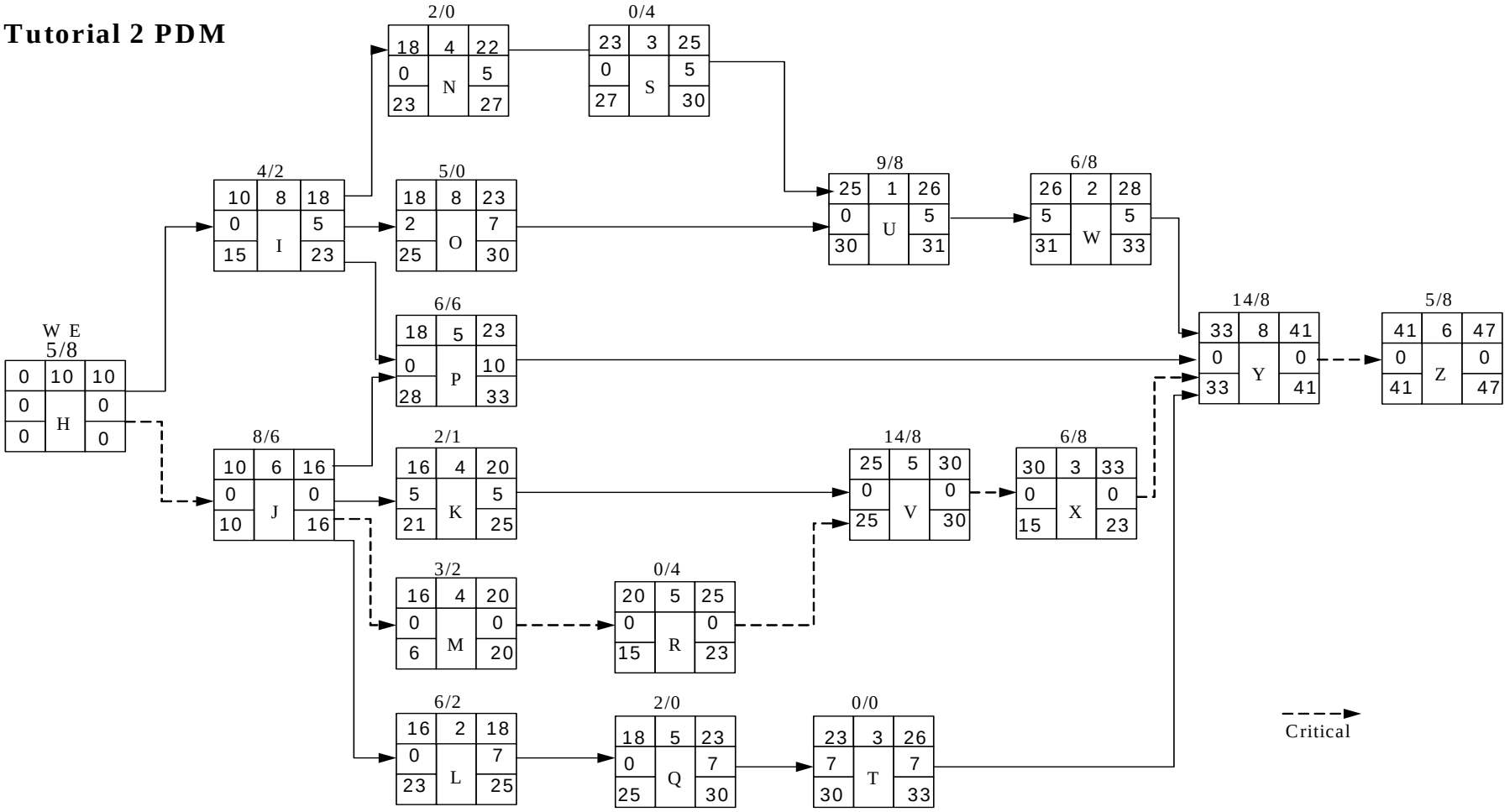
1. If there is a limit of 15 workers per week, smooth the workers loading using ES and LS histogram. Based on the proposed scheduling, plot the equipment loading histogram for the project.

2. Independently of the above resource levelling, schedule the above project based on the following constraints: 14 workers per week and 14 equipment hours per week. What would be the total project completion time?

## Question 1 Solution

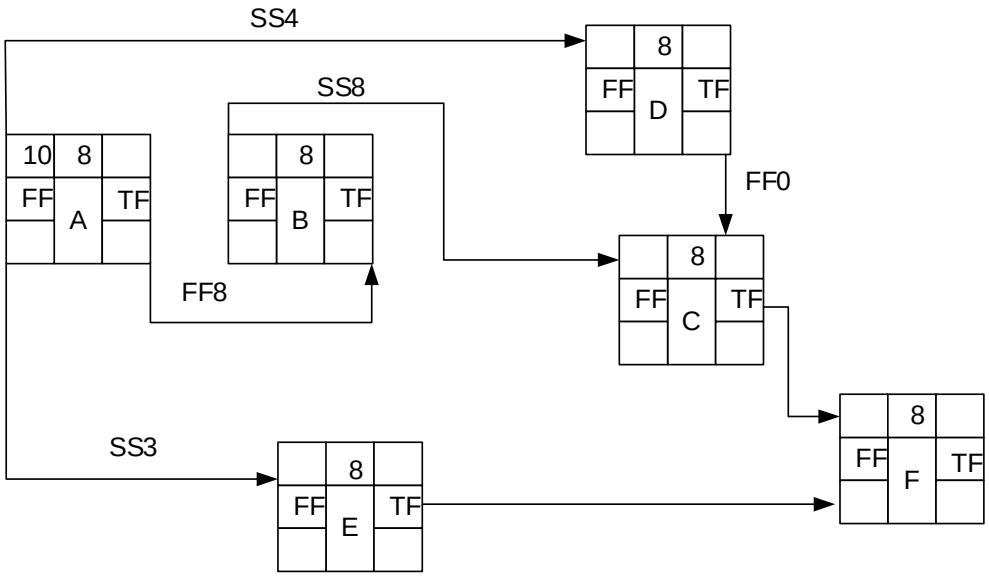


# PDM Solution – Resource histogram not displayed



# Crashing PDM Networks

## Question 1




a) Fully analyse the PDM detailed above and show the critical path? What is the total completion time for the project?

b) The project manager requests that you crash the above network. Based on the following information, which option would you choose to start crashing the network? And why?

| Activity | Normal Duration | Crashed Duration | Extra Cost ($) |
|---|---|---|---|
| **A** | 8 | 6 | $ 10,000 |
| **B** | 8 | 6 | $ 4,000 |
| **C** | 8 | 4 | $ 32,000 |

## Question 2

The information given in the Table below relates to a construction project for which your company is about to sign a contract. The normal duration, cost, crash duration and crash cost for each activity have been derived from the best available resources. Each activity may be reduced to the crash duration in daily stages at a pro-rata cost. Indirect cost is assumed to be $500 per day.

| Activity | Preceding activity | Duration (days) | | Direct Cost ($) | |
|---|---|---|---|---|---|
| | | Normal | Crash | Normal | Crash |
| A | --------- | 15 | 12 | 4500 | 5250 |
| B | --------- | 19 | 14 | 4000 | 4500 |
| C | --------- | 9 | 5 | 2500 | 4500 |
| D | A | 6 | 5 | 1700 | 1940 |
| E | A | 14 | 9 | 4300 | 5350 |
| F | B & D | 9 | 6 | 2600 | 3440 |
| G | C | 8 | 3 | 1800 | 3400 |
| H (End) | E, F, & G | 0 | 0 | 0 | 0 |

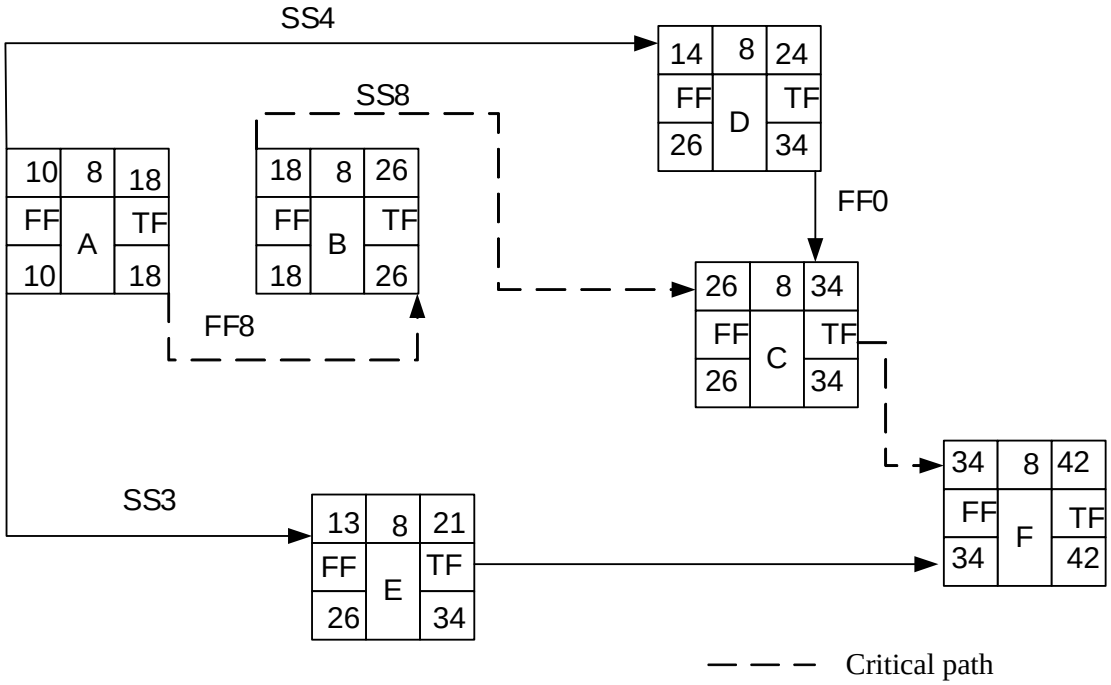
(a) Draw clearly the network, indicate the critical path and state the normal duration and cost for the project.

(b) Calculate the minimum total cost, showing clearly your workings, and the revised duration and cost for each activity.

# Crashing PDM Networks Solutions

## Question 1 Solution

a)




**Total time = 42 days, Critical Path = A→B→C→F**

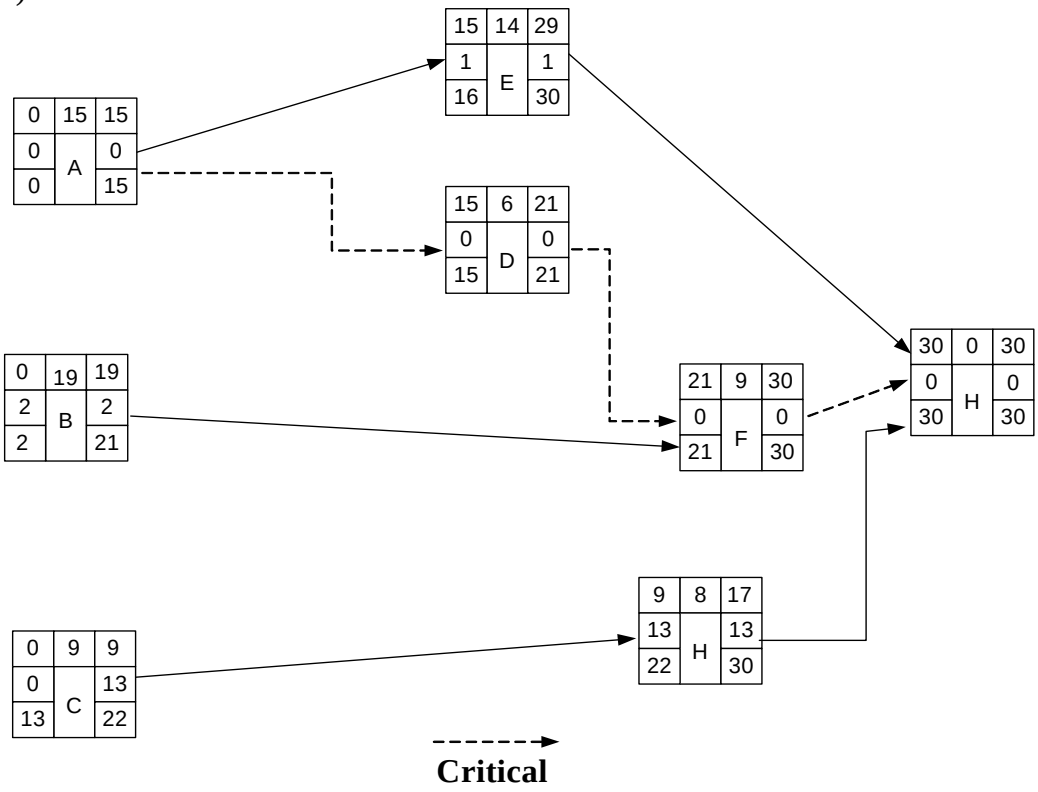
b)

| Activity | Normal Duration | Crashed Duration | Extra Cost ($) | Days saved | Cost Slope $/day |
|---|---|---|---|---|---|
| **A** | 8 | 6 | $ 10,000 | 2 | 5000 |
| **B** | 8 | 6 | $ 4,000 | 2 | 2000 |
| **C** | 8 | 4 | $ 32,000 | 2 | 8000 |

Start by crashing activity A. Activity B to be cheaper, however due to the FF relationship between A & B & the SS between B & C, crashing B actually lengthens the project. Therefore, I choose to crash activity A.

## Question 2 Solution

a)




- Critical path: A, D, F, and H → **30 days**
- Normal direct cost = 4500 + 4000 + 2500 + 1700 + 4300 + 2600 + 1800 = **$21,400**
- Normal indirect cost = 30 × 500 = **$15,000**
- Hence, **Total = $36,400**

b)

| Activity | Extra cost / day |
|---|---|
| A | 750 / 3 = 250 |
| B | 500 / 5 = 100 |
| C | 2000 / 4 = 500 |
| D | 240 /1 = 240 |
| E | 1050 / 3 = 350 |
| F | 840 / 3 =280 |
| G | 1600 / 5 = 320 |
| H | N/A |

Crash D fully
Duration = 29 days
New cost = (29 × 500) + (4500 + 4000+ 2500 + 1940 + 4300 + 2600 +1800) = 21,640 + 14,500 = $36,140 **(Save = $260 for 29 days)**

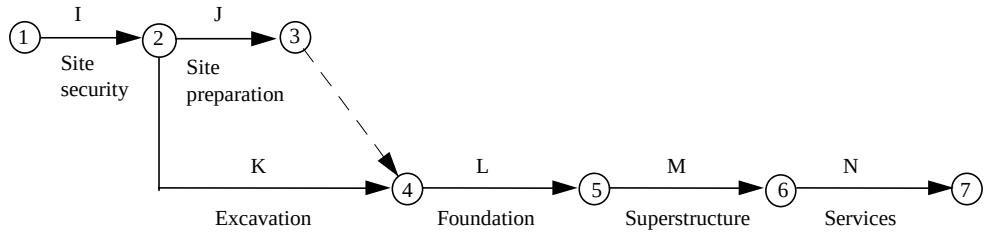
Crash A + 2 of B
Duration = 26 days
New cost = (26×500) + (5200 + 4200 +2500 + 2940 + 4300 + 2600 +1800) = **$35,590**
**(Save = $810 for 26days)**

Can't crashed E & F as these need to be both crashed to reduce completion time and have a cost which is 500 > (i.e. 293.3+320) = 613.3/day

# Line of Balance

## Question 1

Thirty (30) concrete block units are to be built. The simple network for each is given in the Figure below:




Labour details for the project are provided in the Table below:

| Activity | Description | Ideal gang size | Labour hours req. per unit |
|---|---|---|---|
| **I** | **Site security** | **5** | **240** |
| **J** | **Site preparation** | **3** | **50** |
| **K** | **Excavation** | **2** | **60** |
| **L** | **Foundation** | **3** | **120** |
| **M** | **Superstructure** | **6** | **180** |
| **N** | **Services** | **3** | **200** |

(a) Prepare a line of balance (LOB) diagram for the project using a target rate of completion of 5 units per week. Use minimum buffer times of 3 days, and a 5 day 40 hour working week. **Note**: round activity and elapsed time durations (up or down) to the nearest day.

(b) Indicate the total project duration clearly and then suggest any changes that could lead to a more effective schedule.

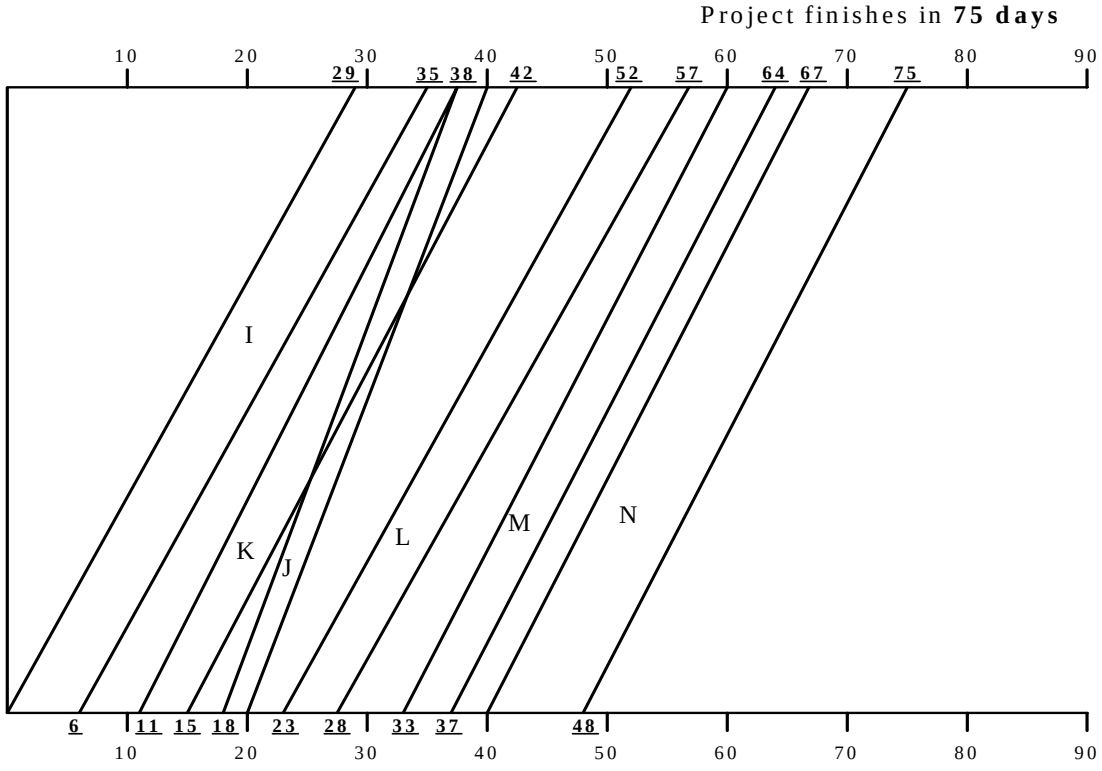
# Line of Balance Solution

## Question 1 Solution

- No = 30 Concrete block units
- Target rate = 5 units per week
- Buffer = 3 days
- 5 days 40 hr working week

| Act | Ideal gang size | Labour hrs/units | Theoretical gang size | Actual gang size | Actual rate of output units / wk | Time per activity (days) | Elapsed time to completion |
|---|---|---|---|---|---|---|---|
| I | 5 | 240 | 30 | 30 | 5 | 6(6) | 29 |
| J | 3 | 50 | 6.25 | 9 | 7.2 | 2.08 (2) | 20.14 (20) |
| K | 2 | 60 | 7.5 | 8 | 5.33 | 3.75 (4) | 27.2 (27) |
| L | 3 | 120 | 15 | 15 | 5 | 5 (5) | 29 (29) |
| M | 6 | 180 | 22.5 | 24 | 5.33 | 3.75 (4) | 27.2 (27) |
| N | 3 | 200 | 25 | 27 | 5.4 | 8.33 | 26.9 (27) |

Theoretical gang size (I) = (5 units/wk × 240) / (40 hrs/wk) = 30
Actual rate of output (I) = (30/30 ×5) = 5
Time per activity (I) = (240/(5×8)) = 6
Elapsed time (I) = ((30-1)×5)/5 = 29



# Queuing Theory and Simulation

## Question 1

If customers arrive at the average rate of 10 per hour and the average service rate is 16 customers per hour. Find the expected number of customers in the system, in the queue and determine the average time a customer spends in the queue awaiting service.

## Question 2

A survey to study the arrival times for concrete trucks arriving on site and concrete discharge reveals the following:

Probability data for discharging concrete: 10% chance of 2 minutes, 20% chance of 3 minutes, 20% chance of 4 minutes, 40% chance of 5 minutes and 10% chance of 10 minutes.

Probability data for concrete truck arrival times: 10% chance of 2 minutes, 15% chance of 3 minutes, 30% chance of 4 minutes, 25% chance of 5 minutes, 20% chance of 6 minutes.

Use the above data to help decide whether 2 loading bays for the concrete trucks is sufficient. Unloading space on the site is highly restricted and you are concerned that two loading bays may be too many. On the other hand, you do not want to provide insufficient loading bays. Use Monte Carlo simulation to help you estimate likely loading bay utilisation.

# Queuing Theory and Simulation - Solutions

## Question 1 Solution

Arrival Rate $= l = 10/hr$
Service Rate $= \mu = 16/hr$

a) No in system $= N = \frac{l}{\mu - l} = \frac{10}{16-10} = 1.67$ *Customurs*

b) No in queue $= N = \frac{l^2}{\mu(\mu - l)} = \frac{10^2}{16(16-10)} = 1.042$ *Customurs*

c) Time in system $= T = \frac{1}{\mu - l} = \frac{1}{16-10} = 0.167\ hr = 10\,\text{min}$

d) Time in queue $= T_g = \frac{l}{\mu(\mu - l)} = \frac{10}{16(16-10)} = 0.104\ hr = 6.25\,\text{min}$

## Question 2 Solution

**Arrival random numbers:**

| Arrival time intervals | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Frequency (%) | 10 | 15 | 30 | 25 | 20 |
| Random numbers for interval | 0-9 | 10-24 | 25-54 | 55-79 | 80-99 |

| Truck No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Random No | 78 | 2 | 9 | 80 | 68 | 57 | 88 | 75 | 61 | 33 |
| Arrival time | 5 | 2 | 2 | 6 | 5 | 5 | 6 | 5 | 5 | 4 |

**Discharge random numbers:**

| Discharging concrete | 2 | 3 | 4 | 5 | 10 |
|---|---|---|---|---|---|
| Frequency (%) | 10 | 20 | 20 | 40 | 10 |
| Random numbers for interval | 0-9 | 10-29 | 30-49 | 50-89 | 90-99 |

| Truck No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Random No | 23 | 64 | 49 | 95 | 4 | 60 | 8 | 52 | 87 | 91 |
| Arrival time | 3 | 5 | 4 | 10 | 2 | 5 | 2 | 5 | 5 | 10 |

**Note**: random numbers have been provided.

Simulating arrival and departure for 10 trucks. For example, truck number 1 arrives at minute five (5) and takes three (3) minutes to discharge and leaves at minute eight (8). Truck number two arrives at minute 5 + 2 = 7 (see above arrival table above for truck number 2) and takes five (5) minutes to discharge concrete and leaves at minute twelve (12).

Thus, when the second truck arrives at minute 7 the first truck is still there (i.e. till minute 8 thus two bays are required). Continuing this type of simulation we can determine that **two bays is sufficient**.

| **Arrive time** | | **Discharge** | **Total time** | **Time in bays** | **Bays required** |
|---|---|---|---|---|---|
| 5 | + | 3 | = 8 | 5-8 | 1 |
| 5 + 2 = 7 | + | 5 | = 12 | 7-12 | 2 |
| 7 + 2 = 9 | + | 4 | = 13 | 9-13 | 2 |
| 9 + 6 = 15 | + | 10 | = 25 | 15-25 | 1 |
| 15 + 5 = 20 | + | 2 | = 22 | 20-22 | 2 |
| 20 + 5 = 25 | + | 5 | = 30 | 25-30 | 2 |
| 25 + 6 = 31 | + | 2 | = 33 | 31-33 | 1 |
| 31 + 5 = 36 | + | 5 | = 41 | 36-41 | 1 |
| 36 + 5 = 41 | + | 5 | = 46 | 41-46 | 2 |
| 41 + 4 = 45 | + | 10 | = 55 | 45-55 | 2 |

# Matrix Reduction Method

## Question 1

Firms A, B, C and D each submit tenders for four (4) contracts C1, C2, C3 and C4 for which bids were invited. The bids are indicated in the following table. Given that each firm is to be allocated one contract, obtain a plan to minimise the total cost. Bids are in $ 000's.

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| Firm A | 16 | 14 | 17 | 12 |
| Firm B | 18 | 12 | 11 | 18 |
| Firm C | 14 | 14 | 17 | 15 |
| Firm D | 16 | 17 | 15 | 16 |

## Question 2

Given the performance matrix shown below, allocate persons A, B, C and D to tasks I, II, III and IV. A plan is required which will give the lowest overall value, i.e. the sum of the four pairings selected has to be minimised. The highest skill graded 1 and the lowest skill graded 9.

| | I | II | III | IV |
|---|---|---|---|---|
| Person A | 8 | 5 | 2 | 1 |
| Person B | 5 | 8 | 6 | 2 |
| Person C | 6 | 9 | 5 | 3 |
| Person D | 2 | 4 | 1 | 5 |

## Question 3

Five dragline excavators (I, II, III, IV and V) are to be put on excavation jobs. The cost of earthwork per cubic metre with each machine on each job is given in the following Table:

| | JOBS | | | | |
|---|---|---|---|---|---|
| MACHINES | A | B | C | D | E |
| I | 100 | 80 | 90 | 140 | 110 |
| II | 130 | 160 | 110 | 120 | 140 |
| III | 30 | 20 | 30 | 40 | 50 |
| IV | 180 | 140 | 150 | 170 | 160 |
| V | 70 | 80 | 90 | 80 | 70 |

Find the optimal allocation(s) of the five machines to jobs and the average cost of earthwork per cubic metre resulting from the allocation of the machines. (Note: must use the matrix reduction method).

# Matrix Reduction Method Solutions

## Question 1 Solution

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| Firm A | 16 | 14 | 17 | 12 |
| Firm B | 18 | 12 | 11 | 18 |
| Firm C | 14 | 14 | 17 | 15 |
| Firm D | 16 | 17 | 15 | 16 |

Step 1: Subtract smallest number in each row from others in that row (typically you would also do this step for columns but this is not necessary in this case due to a zero in each column)

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| Firm A | 4 | 2 | 5 | 0 |
| Firm B | 7 | 1 | 0 | 7 |
| Firm C | 0 | 0 | 3 | 1 |
| Firm D | 1 | 2 | 0 | 1 |

Step 2: Connect zeros by vertical & horizontal lines

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| Firm A | 4 | 2 | 5 | 0 |
| Firm B | 7 | 1 | 0 | 7 |
| Firm C | 0 | 0 | 3 | 1 |
| Firm D | 1 | 2 | 0 | 1 |

Step 3: Subtract smallest number not covered from every other uncovered number and try to get four lines

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| Firm A | 3 | 1 | 5 | 0 |
| Firm B | 6 | 0 | 0 | 7 |
| Firm C | 0 | 0 | 4 | 2 |
| Firm D | 0 | 1 | 0 | 1 |

Step 4: **N = 4** – we can now find the optimum solution(s)

| | Option1 | | | Option2 | |
|---|---|---|---|---|---|
| Firm A | C4 | 12 | Firm A | C4 | 12 |
| Firm B | C3 | 11 | Firm B | C2 | 12 |
| Firm C | C2 | 14 | Firm C | C1 | 14 |
| Firm D | C1 | 16 | Firm D | C3 | 15 |
| | | **Σ 53** | | | **Σ 53** |

## Question 2 Solution

| | I | II | III | IV |
|---|---|---|---|---|
| Person A | 8 | 5 | 2 | 1 |
| Person B | 5 | 8 | 6 | 2 |
| Person C | 6 | 9 | 5 | 3 |
| Person D | 2 | 4 | 1 | 5 |

Step 1:
a) **Rows**

| | I | II | III | IV |
|---|---|---|---|---|
| Person A | 7 | 4 | 1 | 0 |
| Person B | 3 | 6 | 4 | 0 |
| Person C | 3 | 6 | 2 | 0 |
| Person D | 1 | 3 | 0 | 4 |

b) **Columns**

| | I | II | III | IV |
|---|---|---|---|---|
| Person A | 6 | 1 | 1 | 0 |
| Person B | 2 | 3 | 4 | 0 |
| Person C | 2 | 3 | 2 | 0 |
| Person D | 0 | 0 | 0 | 4 |

Step 2:
**Connect O's:**

| | I | II | III | IV |
|---|---|---|---|---|
| Person A | 6 | 1 | 1 | 0 |
| Person B | 2 | 3 | 4 | 0 |
| Person C | 2 | 3 | 2 | 0 |
| Person D | 0 | 0 | 0 | 4 |

Step 3: Subtract smallest number not covered from every other uncovered number
a)

| | I | II | III | IV |
|---|---|---|---|---|
| Person A | 5 | 0 | 0 | 0 |
| Person B | 1 | 2 | 3 | 0 |
| Person C | 1 | 2 | 1 | 0 |
| Person D | 0 | 0 | 0 | 5 |

**N = 3**

b)

| | I | II | III | IV |
|---|---|---|---|---|
| Person A | 5 | 0 | 0 | 1 |
| Person B | 0 | 1 | 2 | 0 |
| Person C | 0 | 1 | 0 | 0 |
| Person D | 0 | 0 | 0 | 6 |

**N = 4**

Step 4: Optimum solution(s)

| | Option1 | | | Option2 | |
|---|---|---|---|---|---|
| Person A | II | 5 | Person A | III | 2 |
| Person B | I | 5 | Person B | IV | 2 |
| Person C | IV | 3 | Person C | I | 6 |
| Person D | III | 1 | Person D | II | 4 |
| | | **Σ 14** | | | **Σ 14** |

## Question 3 Solution

| | JOBS | | | | |
|---|---|---|---|---|---|
| **MACHINES** | **A** | **B** | **C** | **D** | **E** |
| **I** | 100 | 80 | 90 | 140 | 110 |
| **II** | 130 | 160 | 110 | 120 | 140 |
| **III** | 30 | 20 | 30 | 40 | 50 |
| **IV** | 180 | 140 | 150 | 170 | 160 |
| **V** | 70 | 80 | 90 | 80 | 70 |

**Step 1: Rows**

| | JOBS | | | | |
|---|---|---|---|---|---|
| **MACHINES** | **A** | **B** | **C** | **D** | **E** |
| **I** | 20 | 0 | 10 | 60 | 30 |
| **II** | 20 | 50 | 0 | 10 | 30 |
| **III** | 10 | 0 | 10 | 20 | 30 |
| **IV** | 40 | 0 | 10 | 30 | 20 |
| **V** | 0 | 10 | 20 | 10 | 0 |

**Step 2: Columns (3 lines can be drawn after)**

| | JOBS | | | | |
|---|---|---|---|---|---|
| **MACHINES** | **A** | **B** | **C** | **D** | **E** |
| **I** | 20 | 0 | 10 | 50 | 30 |
| **II** | 20 | 50 | 0 | 0 | 30 |
| **III** | 10 | 0 | 10 | 10 | 30 |
| **IV** | 40 | 0 | 10 | 20 | 20 |
| **V** | 0 | 10 | 20 | 0 | 0 |

**Step 3: Lowest number not covered = 10**

| | JOBS | | | | |
|---|---|---|---|---|---|
| **MACHINES** | **A** | **B** | **C** | **D** | **E** |
| **I** | 10 | **0** | **0** | 40 | 20 |
| **II** | 20 | 60 | **0** | 0 | 30 |
| **III** | **0** | **0** | **0** | **0** | 20 |
| **IV** | 30 | **0** | **0** | 10 | 10 |
| **V** | **0** | 20 | 20 | **0** | **0** |

**Answer**

I B or C
II C or D
III A, B, C or D
IV B or C
V A, D or E

**2 Solutions**

| | | |
|---|---|---|
| I | C | 90 |
| II | D | 120 |
| III | A | 30 |
| IV | B | 140 |
| V | E | 70 |
| | **Sum** | **450** |

| | | |
|---|---|---|
| I | B | 80 |
| II | D | 120 |
| III | A | 30 |
| IV | C | 150 |
| V | E | 70 |
| | **Sum** | **450** |

Average = 450/5 = $90 per square metre

# Decision Making

## Question 1

A construction firm decided to purchase a mechanical digger and obtained the following information regarding purchase price, resale values and running costs.

| Year | Purchase price at the start of the year | Resale value at the end of the year | Running costs during the year |
|---|---|---|---|
| 1 | 100 | 80 | 20 |
| 2 | 90 | 70 | 20 |
| 3 | 80 | 50 | 30 |
| 4 | 60 | 20 | 30 |
| 5 | 30 | 0 | 40 |

By preparing a table of suitable values and ignoring inflation/interest rate, etc. determine the optimal time to buy and sell the digger in order to minimise the total annual costs.

## Question 2

A managing director of PMT P/L is considering whether or not to build more manufacturing plants in QLD. His decision is summarised in the following table:

| Alternative | Favourable Market | Unfavourable Market |
|---|---|---|
| Build large plant | $400,000 | -$300,000 |
| Build small plant | $80,000 | -$10,000 |
| Don't build | 0 | 0 |
| Market probabilities | 0.4 | 0.6 |

a) Construct an opportunity loss table
b) Determine EOL and the best strategy
c) What is the expected value of perfect information?

## Question 3

A contractor is considering a large construction project to be executed on the bank of a stream. Initial studies show that temporary works could be constructed to protect the work site at an estimated cost of $100,000. If temporary works are not constructed and there is a flood in the stream, the resulting damages are estimated to be in the order of $150,000. As an alternative, constructing the temporary works could be postponed till such time as would indicate possibility of a flood through rising water level in the stream. For this the contractor would have to keep urgent equipment and materials for prompt timely action. The cost of maintaining these arrangements is likely to be $30,000 but as a result, the damages could be reduced to $80,000. If a flood possibility is about 50%, what strategy should be adopted to minimise the loss and what would be the average value of this loss?

# Decision Making - Solutions

## Question 1 Solution

Ownership matrix

| Year | Purchase | 0<br>100 | 1<br>90 | 2<br>80 | 3<br>60 | 4<br>30 |
|---|---|---|---|---|---|---|
| 1 | 80 | **20** | | | | |
| 2 | 70 | 30 | **20** | | | |
| 3 | 50 | 50 | 40 | **30** | | |
| 4 | 20 | 80 | 70 | 60 | **40** | |
| 5 | 0 | 100 | 90 | 80 | 60 | **30** |

Operation matrix

| | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1 | **20** | | | | |
| 2 | 40 | **20** | | | |
| 3 | 70 | 50 | **30** | | |
| 4 | 100 | 80 | 60 | **30** | |
| 5 | 140 | 120 | 100 | 70 | **40** |

**Total ownership cost/yr**

| | 0 | | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (20+30)/1 | 40 | | | | | | | | |
| ***2*** | ***(30+40)/2*** | ***35*** | (20+20)/1 | 40 | | | | | | |
| 3 | (50+70)/3 | 40 | (40+50)/2 | 45 | (30+30)/1 | 90 | | | | |
| 4 | (80+100)/4 | 45 | (70+80)/3 | 50 | (60+60)/2 | 60 | (30+40)/2 | 70 | | |
| 5 | (100+140)/5 | 45 | (90+120)/4 | 52.5 | (80+100)/3 | 60 | (60+70)/2 | 65 | (30+40)/1 | 70 |

**Answer = Buy new and sell after 2 years, $35,000 per year**

## Question 2 Solution

EOL = **E**xpected **O**pportunity **L**ost
EMV = **E**xpected **M**onetary **V**alue
EVPI = **E**xpected **V**alue of **P**erfect **I**nformation

a) Set up EOL table

| | | Favourable | Unfavourable |
|---|---|---|---|
| A | Large Plant | \$400000-400000 = 0 | 0-(-300000)=\$300000 |
| B | Small Plant | \$400000-80000 = \$32000 | 0-(-10000)=\$10000 |
| C | No Plant | \$400000-0 = \$400000 | 0-(-0)=\$0 |
| Probability | | 0.4 | 0.6 |

b) Calculating EOL

Large Plant = 0.4(0) + 0.6(300000) = $ 180000
Small Plant = 0.4(320000) + 0.6(10000) = $ 134000
No Plant = 0.4(400000) + 0.6(0) = $ 160000

**Hence, choose minimum opportunity loss = $134000**
***∴ Build small plant***

c) Expected value of perfect information

EVPI = EP(**E**xpected value with **P**erfect information) - EMV
EMV(A) = 0.4(400000) + 0.6(-300000) = $-20000
EMV(B) = 0.4(80000) + 0.6 (-10000) = $26000

Choose max EMV = B = $26000

EP = Σ (best outcome for boom / recession) × (probability of occurrence)

EP= 0.4(400000) + 0.6(0) = $160000

***∴ EVPI = $160000 - $26000 = 134000***

**Question 3 Solution**

| Plan | Flood | No Flood |
|---|---|---|
| Build temp works | 0 | 100,000 |
| No temp works | 150,000 | 0 |
| No temp works but keep ready | 80,000 | 30,000 |

EMV (1) = 0.5 (0) + (0.5) (100,000) = 50,000
EMV (2) = 0.5(150,000) + 0.5(0) = 75,000
EMV (3) = 0.5 (80,000) + 0.5 (30,000) = 55,000

**Choose plan A (Build temp works)**

# Inventory Management

## Question 1

a) Your construction firm orders a particular product from a supplier for $6 per tonne. Considering that the annual demand for the material is 7000 tonnes and stock holding costs are 30% per year of the material cost and the cost per order is $6. Calculate the most economical quantity to order?

b) The supplier has offered to provide your firm with a discount for ordering greater quantities of material, as follows. For this new situation, what would be the most economical order quantity?

| **Price per ton ($)** | 6.00 | 5.90 | 5.80 | 5.70 | 5.60 |
|---|---|---|---|---|---|
| **Tons brought** | 1-299 | 300-799 | 800-1999 | 2000-3999 | Over 4000 |

## Question 2

The demand for a particular product is 12,000 units per year. The costs associated with ordering include fixed salaries and costs of $4,000 per annum and variable costs of $30 per order. Storage costs consist of rent of $2000 per annum and variable costs at the rate of $25 per unit of product. Calculate the economic order quantity with replenishment taking place of the whole order at the same time.

## Question 3

The raw material needed by a company for its operation costs $200 per ton and has associated with it a cost of $200 for each delivery made. Variable costs of storage are 5 per cent per year of value of stock held. A further storage cost arises in that special containers have to be hired in which to store the material. These must be hired for at least a year at a time and the hire cost per year is $1000. Each container is capable of holding 320 tons of material. If the total demand per year is 100,000 tons, determine the optimum reorder quantity.

## Question 4

A company has an annual demand of 10,000 units, which can be obtained from either an outside supplier or a subsidiary company. Assuming that the delivery time is constant, use the data set out in the following table, to calculate which option should the company select?

| | From outside supplier | From subsidiary company |
|---|---|---|
| Purchase price ($), per unit | 12 | 12.1 |
| Storage cost ($) | 2 | 1 |
| Cost of ordering ($) | 30 | 20 |

## Question 5

Your company uses 500,000 items of a certain component per annum at a fairly uniform rate. The supplier ABC Pty Ltd. charges your company $100 per 5000 units. Ordering cost is $50 regardless of the size of the order. Your current order policy is to order 10,000 items every week, but the newly appointed manager criticised such frequent ordering. As a consequence of this criticism, the manager asked you to determine:

(a) The average quantity of stock currently held, and how much does this cost the company each year in holding costs assuming that it costs $0.125 p.a. to hold one item in stock.
(b) How many orders are made each year, and what does this cost the company assuming 50 working weeks/year.
(c) The economic order quantity (EOQ) and associated cost savings if this order quantity was used rather than the current order of 10,000.
(d) Whether it is worth ordering a larger quantity of 50,000 to take advantage of the reduced price of $90 per 5000 units offered by ABC (compared to EOQ situation).

# Inventory Management Solutions

## Question 1 Solution

a)

$$Annual\ order\ \cos t = \frac{cd}{q},\ Annual\ hold\ \cos t = (ip)\frac{Q}{2}$$

$$d = 7000t,\ c = \$6,\ i = 0.3,\ p = \$6$$

$$\therefore Q = \sqrt{\frac{2cd}{ip}} = \sqrt{\frac{2\times 6\times 7000}{0.3\times 6}} = 216t$$

b)

| Batch size | cd/Q<br>Ordering cost | (ip)Q/2<br>Holding cost | Material cost | Total cost |
|---|---|---|---|---|
| 216.025 | 194.42 | 194.423 | 42000 | 42388.84 |
| 300 | 140 | 265.5 | 41300 | 41705.5 |
| 800 | 52.5 | 696 | 40600 | 41348.5 |
| 2000 | 21 | 1710 | 39900 | 41631 |
| 4000 | 10.5 | 3360 | 39200 | 425705 |

**Based on the above the most economical order quantity is 800t**

## Question 2 Solution

Based on the stock control equations in the notes:

Demand $= d = 12000\ units / yr$
Fixed services $= \$4000 / yr$
Variable costs $= c = \$30 / order$
Storage rental $= \$2000$
Variable costs $= ip = \$25 / unit$

**Calculate EOQ;**

$$Q = \sqrt{\frac{2cd}{ip}} = \sqrt{\frac{2\times 30\times 12000}{25}} = 169.17 \cong 170 units$$

## Question 3 Solution

Demand $= d = 100000\ tonnes$
Cost per unit $= p = \$200 / tonnes$
$C = \$200\ per\ order$

$ip = 5\% \times 200 = (0.05 \times 200)$

$\text{Ordering cost} = \frac{cd}{Q}$

But for the holding cost must should also consider the cost of the container:

$$\text{Holding cost} = \frac{ipQ}{2} + \frac{Q \times 1000(\$/container)}{320\,t/container}$$
$$= \frac{200 \times 100000}{Q} = 5Q + 3.125Q$$
$$= 8.125Q^2 = 2 \times 10^7$$
$$= 1569\,t$$

**Question 4 Solution**

**Option 1**

$d = 10000$

$c = \$30$

$ip = \$2$

$Q_1 = \sqrt{\frac{2cd}{ip}} = 547.72 \cong 548$

Unit cost = cost / unit × demand
$= \$12 \times 10000$
$= 120000$

Ordering = No of orders /yr × cost/yr
$= \frac{cd}{Q} = \frac{10000 \times 30}{548}$
$= 547.45$

Storing $= ip \times d = 2 \times 10000$
$= 20000$

**Hence Option 1**

$= 120000 + 547.45 + 20000$
$= 140574.45$

**Option 2**

$d = 10000$

$c = \$20$

$ip = \$1$

$Q_2 = \sqrt{\frac{2cd}{ip}} = 632.45 \cong 633$

Unit cost = cost / unit × demand
$= \$12.1 \times 10000$
$= 121000$

Ordering = No of orders /yr × cost/yr
$= \frac{cd}{Q} = \frac{10000 \times 20}{633}$
$= 315.96$

Storing $= ip \times d = 1 \times 10000$
$= 10000$

**Hence Option 2**

$= 121000 + 315.96 + 10000$
$= 131315.96$

***Therefore choose Option 2 (lowest)***

## Question 5 Solution

**(a)**
Average stock level = Q/2 = 10000/2 = 5000 units
Holding cost = ipQ/2 = (0.125 × 10000)/2 = **$625**

**(b)**
Orders per year = 500000/10000 = **50 orders per year**
Ordering cost = cd/Q = 50 × 500000 / 10000 = $2500
Total cost of ordering and holding for the original situation = 625 + 2500 = **$3125**

**(c)**
EOQ = √2cd/ip = √ (2 × 50 × 500000)/(0.125) = **20,000 units/order**
Holding cost = ipQ/2 = (0.125 × 20000)/2 = $1250
Ordering cost = cd/Q = 50 × 500000 / 20000 = $1250
Total cost of ordering and holding for the original situation = 1250 + 1250 = **$2500**
**Save = 3125 – 2500 = $625 from new situation**

**(d)**
Total cost for **old situation**:
Old situation = (ipQ/2) + cd/Q + (500000/5000 × 100)
Old situation = 1250 + 1250 + 10000 = **$12500**
Total cost for **new situation**:
Q = 50000
New cost = $90 per 5000 units
New Situation = (0.125 × 50000)/2 + (50 × 500000)/50000 + 9000
New Situation = 3125 + 500 + 9000 = **$12625**

**12625 > 12500, therefore the EOQ situation is better**

# Cost Planning

## Question 1

A material supplier company produces 54,000 items per year when working at 60% of the factory's capacity. Each item is sold for $10. The costs involved in the manufacture at this rate of production are as follows:

- Materials $105,000
- Wages $180,000
- Fixed overhead costs $75,000
- Variable overhead costs $45,000

**Note**: Variable overhead is constantly proportionate to the number of items produced.

A contractor places an order with the company for 36,000 additional items at the reduced price of $9.00 each (i.e. now 100% production). Due to the additional quantity of materials that are required, an 8.0% discount on all material prices is obtained. However, the additional labour that is required has to be drawn from a reservoir of untrained labour. As a result, the overall efficiency of labour in production throughout the factory falls by 10% on all production.

(a) Illustrate the variation in profit between the prior and new situation.
(b) Which is the best option, based on percentage profit?

## Question 2

The standard costs for the materials involved in mixing a compound are $0.60 per kg of Material X, $0.75 per kg of Material Y and $0.53 per kg of Material Z. The prices paid for each material in practice are $0.65 per kg, $0.73 per kg and $0.55 per kg, respectively. The specification of the compound calls for a standard mix of 100 kg of X, 270 kg of Y and 135 kg of Z. A check on the material stocks shows that 105 kg, 267 kg and 140 kg respectively are being used in the actual mixing operation. Calculate the material variance for the actual mixing operation.

# Cost Planning Solutions

## Question 1 Solution

### Original Production

Profit = turnover – costs = (54000 × 10) – (105000 + 180000 + 75000 + 45000) = $135000 (from cost of $405,000)

### New Situation

Profit = [54000 × 10 + 36000 × 9.00] – [105000 + (0.4/0.6) × 105000] × 0.92 – [(45000 × 0.4/0.6) + 45000] – [(180000 + 120000) × 1.1] – 75000
Profit = turnover – materials – variable overheads – wages – fixed overheads
Profit = 864000 – 161000 – 75000 – 330000 – 75000 = $223,000 (from cost of $641,000)

Old Situation = Percent Profit = Profit/Total Cost = 135000/405000 = **33.3%**
New Situation = 223,000/641000 = **34.8%**

The new situation is the best based on percentage profit.

## Question 2 Solution

| | X | | Y | | Z | |
|---|---|---|---|---|---|---|
| Standard mix | 100 | | 270 | | 135 | |
| Standard cost/kg | 0.6 | | 0.75 | | 0.53 | |
| Total standard cost | 60 | + | 202.50 | + | 71.55 | = $334.05 |
| Actual mix | 105 | | 267 | | 140 | |
| Paid cost | 0.65 | | 0.73 | | 0.55 | |
| Total paid cost | 68.25 | + | 194.91 | + | 77.0 | = $340.16 |

Material variance = $6.11 (unfavourable)

# 7056ENG

Resource Planning and Management

# Tutorial Questions

Dr Rodney Stewart

# Tutorial 1

Draw the activity-on-arrow network diagram for the following projects, calculate the earliest and latest starting and finishing times for all activities, and hence calculate the total float, free float for each activity.

## Project A

| Activity | Duration | IFA |
|---|---|---|
| A | 22 | D & J |
| B | 10 | C & F |
| C | 13 | D & J |
| D | 8 | ------- |
| E | 15 | C, F & G |
| F | 17 | H, I & K |
| G | 15 | H, I & K |
| H | 6 | D & J |
| I | 11 | J |
| J | 12 | ------- |
| K | 20 | -------- |

## Project B

| Activity | Duration (days) |
|---|---|
| 1-2 | 5 |
| 1-3 | 10 |
| 1-4 | 12 |
| 2-4 | Dummy |
| 2-5 | 14 |
| 3-4 | 6 |
| 3-6 | 13 |
| 4-5 | 7 |
| 4-7 | 11 |
| 5-7 | 17 |
| 5-9 | 9 |
| 6-7 | Dummy |
| 6-8 | 8 |
| 7-8 | 5 |
| 7-9 | 13 |
| 7-10 | 8 |
| 8-10 | 14 |
| 9-10 | 6 |

# Tutorial 2

Draw the PDM network diagram for the following project, calculate the earliest and latest starting and finishing times for all activities, and hence calculate the total float, free float for each activity.

| Activity | IPA | Duration (WEEKS) | WORKERS REQUIRED PER WEEK | EQUIPMENT REQUIRED (hrs/WEEK) |
|---|---|---|---|---|
| H | ---- | 10 | 5 | 8 |
| I | H | 8 | 4 | 2 |
| J | H | 6 | 8 | 6 |
| K | J | 4 | 2 | 1 |
| L | J | 2 | 6 | 2 |
| M | J | 4 | 3 | 2 |
| N | I | 4 | 2 | 0 |
| O | I | 5 | 5 | 0 |
| P | I, J | 5 | 6 | 6 |
| Q | L | 5 | 2 | 0 |
| R | M | 5 | 0 | 4 |
| S | N | 3 | 0 | 4 |
| T | Q | 3 | 0 | 0 |
| U | O, S | 1 | 9 | 8 |
| V | K, R | 5 | 14 | 8 |
| W | U | 2 | 6 | 8 |
| X | V | 3 | 6 | 8 |
| Y | P, W, X, T | 8 | 14 | 8 |
| Z | Y | 6 | 5 | 8 |

1. If there is a limit of 15 workers per week, smooth the workers loading using ES and LS histogram. Based on the proposed scheduling, plot the equipment loading histogram for the project.

2. Independently of the above resource levelling, schedule the above project based on the following constraints: 14 workers per week and 14 equipment hours per week. What would be the total project completion time?

# Tutorial 3

1. If customers arrive at the average rate of 10 per hour and the average service rate is 16 customers per hour. Find the expected number of customers in the system, in the queue and determine the average time a customer spends in the queue awaiting service.

2. The demand for a particular product is 12,000 units per year. The costs associated with ordering include fixed salaries and costs of $4,000 per annum and variable costs of $30 per order. Storage costs consist of rent of $2000 per annum and variable costs at the rate of $25 per unit of product. Calculate the economic order quantity with replenishment taking place of the whole order at the same time.

3. The raw material needed by a company for its operation costs $200 per ton and has associated with it a cost of $200 for each delivery made. Variable costs of storage are 5 per cent per year of value of stock held. A further storage cost arises in that special containers have to be hired in which to store the material. These must be hired for at least a year at a time and the hire cost per year is $1000. Each container is capable of holding 320 tons of material. If the total demand per year is 100,000 tons, determine the optimum reorder quantity.

4. A company has an annual demand of 10,000 units, which can be obtained from either an outside supplier or a subsidiary company. Assuming that the delivery time is constant, use the data set out in the following table, to calculate which option should the company select

| | From outside supplier | From subsidiary company |
|---|---|---|
| Purchase price($), per unit | 12 | 12.1 |
| Storage cost ($) | 2 | 1 |
| Cost of ordering ($) | 30 | 20 |

5. A survey to study the arrival times for concrete trucks arriving on site and concrete discharge reveals the following:

   Probability data for discharging concrete: 10% chance of 2 minutes, 20% chance of 3 minutes, 20% chance of 4 minutes, 40% chance of 5 minutes and 10% chance of 10 minutes.

   Probability data for concrete truck arrival times: 10% chance of 2 minutes, 15% chance of 3 minutes, 30% chance of 4 minutes, 25% chance of 5 minutes, 20% chance of 6 minutes.

   Use the above data to help decide whether 2 loading bays for the concrete trucks is sufficient. Unloading space on the site is highly restricted and you are concerned that two loading bays may be too many. On the other hand, you do not want to provide insufficient loading bays. Use Monte Carlo simulation to help you estimate likely loading bay utilisation.

# Tutorial 4

1. Firms A, B, C and D each submit tenders for four (4) contracts C1, C2, C3 and C4 for which bids were invited. The bids are indicated in the following table. Given that each firm is to be allocated one contract, obtain a plan to minimise the total cost. Bids are in $ 000's.

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| Firm A | 16 | 14 | 17 | 12 |
| Firm B | 18 | 12 | 11 | 18 |
| Firm C | 14 | 14 | 17 | 15 |
| Firm D | 16 | 17 | 15 | 16 |

2. Given the performance matrix shown below, allocate persons A, B, C and D to tasks I, II, III and IV. A plan is required which will give the lowest overall value, i.e. the sum of the four pairings selected has to be minimised. The highest skill graded 1 and the lowest skill graded 9.

| | I | II | III | IV |
|---|---|---|---|---|
| A | 8 | 5 | 2 | 1 |
| B | 5 | 8 | 6 | 2 |
| C | 6 | 9 | 5 | 3 |
| D | 2 | 4 | 1 | 5 |

3. A construction firm decided to purchase a mechanical digger and obtained the following information regarding purchase price, resale values and running costs

| Year | Purchase price at the start of the year | Resale value at the end of the year | Running costs during the year |
|---|---|---|---|
| 1 | 100 | 80 | 20 |
| 2 | 90 | 70 | 20 |
| 3 | 80 | 50 | 30 |
| 4 | 60 | 20 | 30 |
| 5 | 30 | 0 | 40 |

By preparing a table of suitable values and ignoring inflation/interest rate, etc. determine the optimal time to buy and sell the digger in order to minimise the total annual costs.

4. A managing director of PMT P/L is considering whether or not to build more manufacturing plants in QLD. His decision is summarised in the following table:

| Alternative | Favourable Market | Unfavourable Market |
|---|---|---|
| Build large plant | $400,000 | – $300,000 |
| Build small plant | $80,000 | – $10,000 |
| Don't build | 0 | 0 |
| Market probabilities | 0.4 | 0.6 |

a) Construct an opportunity loss table
b) Determine EOL and the best strategy
c) What is the expected value of perfect information?

# Tutorial 5

## Question 1: Crashing Networks

| Activity | IFA | Normal Time | Normal Cost /day | Crashed Cost /day | Crashed Time |
|---|---|---|---|---|---|
| A | B | 5 | 5,000 | - | NA |
| B | C, D | 10 | 20,000 | 25,000 | 8 |
| C | F | 3 | 4,000 | 6,000 | 2 |
| D | E | 15 | 20,000 | 28,000 | 10 |
| E | G | 7 | 6,000 | 9,000 | 5 |
| F | G | 15 | 20,000 | 26,000 | 10 |
| G | H | 5 | 2,000 | 3,000 | 3 |
| H | - | 5 | 25,000 | 30,000 | 3 |

a) How much extra will it cost to crash the program by 7 days?
b) The client has offered a bonus of $12,000 for a 35 day completion. It costs $1000/day as overheads. Is this deal worthwhile?

## Question 2: Line of Balance (LOB)

Twenty five (25) concrete block units are to be built. The simple network for each is given in Fig. (1) whereas labour details are given in Table (2).

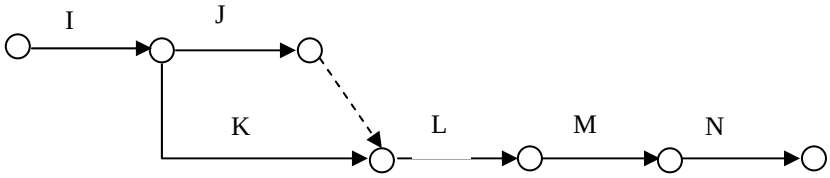



Figure 1: Project Network

| Activity | Description | Ideal gang size | Labour hrs req. per unit |
|---|---|---|---|
| I | Site Security | 6 | 300 |
| J | Site preparation | 3 | 40 |
| K | Excavation | 2 | 50 |
| L | Foundations | 3 | 120 |
| M | Superstructure | 5 | 180 |
| N | Services | 4 | 250 |

Table 2: Labour Details

(a) **Prepare** a line of balance (LOB) diagram for the project using a target rate of completion of 4 units per week. **Use** minimum buffer times of 4 days, and a 5 day 40 hour week.
(b) **Indicate** the total project duration clearly and then **suggest** any changes that could lead to a more effective schedule.

# Tutorial 6

1. A contracting firm is invited to tender for an overseas job. The firm calculates its actual costs to be $5,000,000. The firm, however, agreed that the client will be paying an amount of $2,00,000 at the end of each of the third, fourth and fifth years after construction is commenced, to cover the actual costs of the contractor plus his profit.

   The contractor programmes the work to cover a three-year period and estimates that the costs he will incur will amount to $1,000,000 by the end of the first year, $3,000,000 in total by the end of the second year and $5,000,000 in total by completion of the work at the end of the third year. The contractor estimates that he will have to find all the money to finance the work from sources outside the firm and this will have to be borrowed at an interest rate of 10% per year. Produce a budget statement for the contractor, year by year assuming all payment and receipts are on a year-end basis.

2. A concrete plant produces a compound which, at full capacity, can be sold for a total sum of $1,200,000 per year. The fixed overhead for the plant amounts to $450,000 per year and the total variable costs when at full production are $650,000 per year. By making some minor modifications to the plant the production can be increased by 25% with a 10% increase in fixed overhead. Assume that variable costs are constantly proportionate to productivity. Plot both situations on a break-even chart and comment on your findings.

3. A material supplier company produces 10,000 items per year when working at 50% of the factory's capacity. Each item is sold for $15. The costs involved in manufacture at this rate of production are: $30,000 for materials, $60,000 for wages, $30,000 on fixed overhead and $12,000 on variable overhead. Variable overhead is constantly proportionate to the number of items produced.

   A contractor places an order with the company for 10,000 additional items at the reduced price of $11.75 each. Due to the additional quantity of materials that are required, a 2.5% discount on previous prices is obtained but only for the additional work. On the other hand, the additional labour that is required has to be drawn from a reservoir of untrained labour. As a result, the overall efficiency of labour in production throughout the factory falls by 5% on all production. Illustrate the variation in profit between the prior and new situation.

4. A contractor estimates the cost of a project to be $1,000,000 at current prices. The contractor adds a profit margin of 20% on which he expects to pay tax at a rate of 50%. If inflation is running at 12% per year and the owner fully compensates the contractor for price increases due to inflation but delays payment until 2 months after certification, what is the contractor's true profit margin after tax?

# Tutorial 7 - Revision

## Question 1

Draw clearly the PDM network reflecting the following information and analyse it fully:

| Activity | Duration (days) | IPA | IFA |
|---|---|---|---|
| A | 3 | ---- | B, C |
| B | 5 | A | D, E |
| C | 4 | A | F, I |
| D | 7 | B | G |
| E | 6 | B | H |
| F | 11 | C | H |
| G | 6 | D | K |
| H | 4 | E, F | K |
| I | 3 | C | K, L |
| J | 6 | D | M |
| K | 5 | G, H, I | N |
| L | 7 | I | O |
| M | 5 | J | P |
| N | 3 | K | P |
| O | 2 | L | P |
| P | 4 | M, N, O | ---- |

## Question 2

A building project requires cement at a uniform rate of 400 bags/week over a year period (52 wks). A bag of cement costs $10.0 and the ordering cost is $200. The stock holding cost is 20% of the cost of the item per year. Determine what is the economical quantity for purchase?

## Question 3

Mixed concrete is supplied by a batching and mixing plant to a fleet of trucks, which carry it to different sites of placement. The trucks arrive at the plant at an average rate of 12 per hour and the plant is capable of loading 20 trucks per hour. The plant operates 12 hours/day. Assuming that the truck arrivals are Poisson distributed and loading times are exponentially distributed, determine the following:

(a) The mean time a truck would spend at the plant
(b) The mean number of trucks waiting in the queue to be loaded
(c) Assuming that the plant operating cost is $300.0 per hour, whereas truck drivers value their time at $80.0 per hour, calculate the average total daily cost for this queuing system?

## Question 4

A housing project comprises of 40 units with the target handover rate is 2 units per week to the client. Each unit consists of eight successive (sequential) operations, starting with activity A. Labour details for each activity are given in the table below.

| Activity | Labour hrs required per unit | Ideal gang size |
|---|---|---|
| A | 80 | 2 |
| B | 310 | 3 |
| C | 90 | 2 |
| D | 30 | 2 |
| E | 40 | 2 |
| F | 142 | 4 |
| G | 62 | 2 |
| H | 78 | 2 |

Assuming that there is a minimum buffer of two (2) days between operations, and a 40 hours five-day working week:

(a) Prepare a line of balance (LOB) diagram
(b) Indicate the total project duration clearly
(c) Suggest any changes that could lead to a more effective schedule

## Question 5

a) Draw the PDM network diagram for the following project. Calculate the earliest and latest starting and finishing times for all activities.

| Activity | Duration (days) | IFA |
|---|---|---|
| A | 3 | D |
| B | 4 | E |
| C | 6 | F, G |
| D | 8 | H |
| E | 5 | I |
| F | 2 | I |
| G | 9 | J |
| H | 6 | K |
| I | 1 | L |
| J | 8 | L |
| K | 3 | L |
| L | 0 | --------- |

b) If each activity necessitates the continuous use of a crane, modify the PDM network in view of having access to two cranes.

## Question 6

For a pipe laying operation, trucks delivering the pipes arrive at the average rate of 10 minutes. A crane, on site, takes an average of 7.5 minutes to unload each truck. Using *the single-line theory,* find the utilisation factor for this operation, the average number of trucks in the system and the average time a truck is expected to spend in the queue.

## Question 7

A team of twelve (12) men is employed to unload material from trucks. The team works for a 4-hour period each day, during which 16 trucks arrive. Your observation indicates that it takes 12 minutes to unload a truck and each truck is unloaded on a first-in-first-out basis by all 12 men working as a team (one server). Calculate the cost of this system if the members of the team are each paid $100 for the 4-hour period, and trucks are compensated at the rate of $0.5 per minute, after the first 30 minutes spent in the system.

# Tutorial 8 - Revision

## Question 1

For the following network, determine the **project completion time**. Hint: consider resource constraints.

| Activity | IFA | Duration | Resource Requirements | | |
|---|---|---|---|---|---|
| | | | X | Y | Z |
| A | B | 2 | -- | 3 | 1 |
| B | E | 4 | -- | 2 | -- |
| C | D & H | 2 | 3 | -- | 1 |
| D | F | 5 | -- | 2 | 1 |
| E | J | 1 | 2 | -- | 1 |
| F | J | 4 | 1 | -- | -- |
| G | I | 1 | 2 | -- | -- |
| H | K | 8 | 4 | 2 | 1 |
| I | K | 3 | 5 | - | -- |
| J | L | 3 | -- | 2 | 1 |
| K | L | 5 | 2 | -- | 1 |
| L | -- | 2 | -- | -- | 1 |
| **Maximum Available** | | | **6** | **6** | **2** |

Note - **IFA**: Immediately Following Activity.

## Question 2

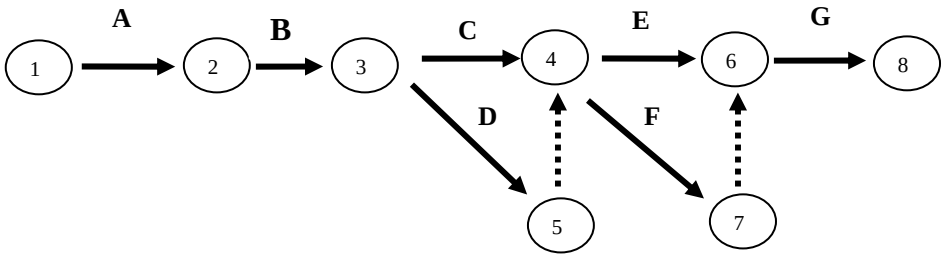
You are responsible for the management and control of a concrete batching plant. Your plant opens on Saturday mornings to service trucks requiring concrete. You have available ten (10) workers to load the concrete trucks. The team works from 8 am till 1 pm without a break (5 hour shift) to load the trucks, during which 15 concrete trucks arrive. Your observation indicates that it takes 10 minutes to load each truck with concrete on a first-in-first-out basis by all 10 men working as a team (one server). Calculate the cost of this system per period (5 hours) if the members of the team are each paid $180 for the 5-hour period, and trucks are compensated at the rate of $6.00 per minute, after the first 10 minutes spent in the system.

## Question 3

Prepare a line of balance schedule for a small contract of 15 houses based on a rate of build of three houses per week assuming a five-day (10 hrs per day) working week. A minimum buffer of three days should be assumed. The following table shows the activities together with the established labour-hours and optimum number of people for each activity.

| Activity | Labour hours required per unit | Optimum gang size |
|---|---|---|
| **A** | 160 | 6 |
| **B** | 320 | 4 |
| **C** | 180 | 4 |
| **D** | 60 | 2 |
| **E** | 60 | 2 |
| **F** | 140 | 3 |
| **G** | 100 | 2 |

The sequence of operation is as follows:




(a) Prepare a line of balance (LOB) diagram for the project.
(b) Indicate the total project duration clearly.
(c) Make two (2) suggestions as to how the overall duration of the project could be reduced.

**Note:** round time per activity and elapsed time (up or down) to the nearest day

**Question 4**

Your company has a demand of 18,000 units of a product, which can be obtained from one of three possible suppliers. Assuming that the delivery time is constant, use the data set out in the following table, to calculate which supplier your company should select.

| | **Supplier** | | |
|---|---|---|---|
| | **A** | **B** | **C** |
| Purchase price ($), per unit | 13 | 13.1 | 13.2 |
| Storage cost ($), per unit | 2.2 | 2.0 | 1.8 |
| Cost of ordering ($) | 120 | 80 | 60 |

## Question 5

| Activity | Duration (weeks) | IPA | Crashed time (weeks) | Normal cost ($000's) | Crashed cost ($000's) |
|---|---|---|---|---|---|
| **A** | 5 | - | N/A | 5 | - |
| **B** | 4 | A | N/A | 3 | - |
| **C** | 5 | A | 4 | 50 | 58 |
| **D** | 7 | A | 5 | 15 | 21 |
| **E** | 6 | A | N/A | 25 | - |
| **F** | 4 | B & C | 3 | 5 | 15 |
| **G** | 3 | E | 1 | 5 | 8 |
| **H** | 3 | F & D | N/A | 4 | - |
| **I** | 6 | E | N/A | 3 | - |
| **J** | 1 | G & H | N/A | 6 | - |
| **K** | 4 | I & J | 3 | 2 | 7 |

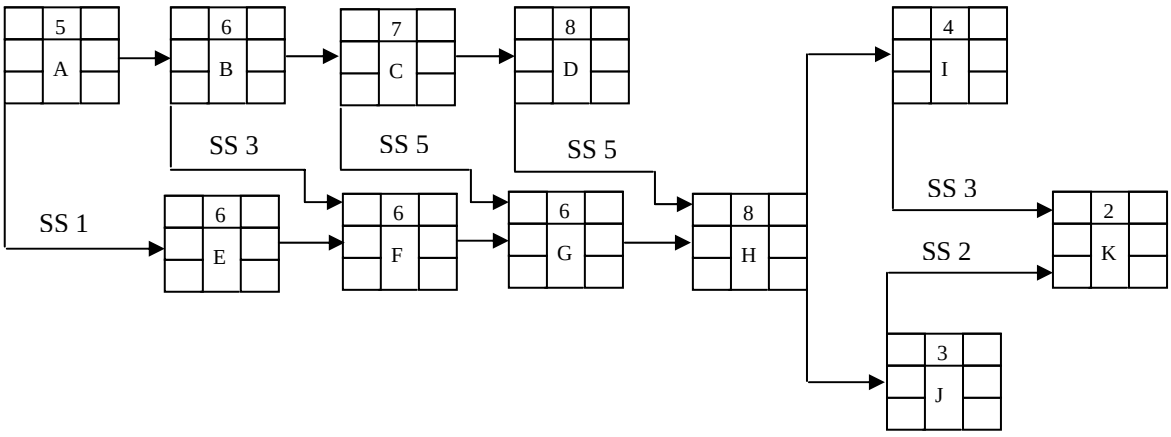
**Note - IPA**: Immediately Preceding Activity, **N/A**: Not Applicable.

a) Draw the PDM network from the above information (pre-crashing) and analyse it fully. How long will the project take, and what are the critical activities?

b) Considering that you save $9,000 in indirect costs for every week's reduction in the projects timeframe. What is the total cost that corresponds to the minimum project duration? **Note**: show clearly your calculations.

## Question 6

For the following network, determine the project completion time if both resources X and Y are limited to 6.




Resources required for each activity are shown in the table:

| **Activity** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Duration (weeks)** | 5 | 6 | 7 | 8 | 6 | 6 | 6 | 8 | 4 | 3 | 2 |
| **Resource X** | 3 | --- | 4 | --- | 4 | --- | 2 | --- | 5 | 4 | 2 |
| **Resource Y** | --- | 4 | --- | 4 | --- | 2 | --- | 2 | --- | --- | --- |

## Question 7

A contractor is considering a large construction project to be executed on the bank of a stream. Initial studies show that temporary works could be constructed to protect the work site at an estimated cost of $90,000. If temporary works are not constructed and there is a flood in the stream, the resulting damages are estimated to be in the order of $165,000.

As an alternative, constructing the temporary works could be postponed till such time as would indicate the possibility of a flood through rising water level in the stream. For this the contractor would have to keep urgent equipment and materials for prompt timely action. The cost of maintaining these arrangements is likely to be $40,000 but as a result, the damages could be reduced to $90,000. If a flood possibility is about 40%, what strategy should be adopted to minimise the loss and what would be the average value of this loss?

## Question 8

The Queensland Department of Main Roads is offering four contracts (A, B, C and D) to be awarded for a small highway project. Five pre-selected contractors have provided their bid submissions for the different contracts as outlined below. Your senior engineer has asked you to determine which company should be awarded each contract to minimise the total project cost. They also stated that each contractor could only receive one of the contracts available.

**Thiess Contractors**:
- Contract A $ 650,000
- Contract B $ 100,000
- Contract C $ 180,000
- Contract D $ 350,000

**Leighton Contractors**:
- Contract A $ 550,000
- Contract B $ 120,000
- Contract C $ 240,000
- Contract D $ 410,000

**Abi Group Contractors**:
- Contract A $ 700,000
- Contract B $ 90,000
- Contract C $ 270,000
- Contract D $ 570,000

**John Holland Contractors:**
- Contract A $ 600,000
- Contract B $ 140,000
- Contract C $ 200,000
- Contract D $ 600,000

**Pavement Contractors**:
- Contract A $ 580,000
- Contract B $ 110,000
- Contract C $ 250,000
- Contract D $ 380,000

a) Determine the assignment of the four contracts to minimise the total project cost?
b) What is the total project cost for this assignment?

# 7056ENG

Resource Planning and Management

# Assignment

Dr Rodney Stewart

# 7056ENG

Resource Planning and Management

# Civil/Construction Assignment

Dr Rodney Stewart

**Major Assignment – Built Environment Project**

7056ENG Resource Planning and Management

Semester 2 – 2006

*Lecturer*: Dr Rodney Stewart

*Due Date*: Friday 27th October 2006 (Week 13 Lecture time)

**What is required?**

A 10,000 word major assignment on the resource planning and management for a luxury residence being constructed in Main Beach (see plans).

**What should the assignment include?**

- A review of the provided plans.
- An itemised list of the tasks required for constructing the building and its surroundings.
- A work breakdown structure (WBS) for the proposed project.
- A detailed estimate of the resources required for each activity (Labour, machinery, materials, supervision etc.). Allocate costs to each activity in the WBS.
- A PDM diagram for the project (utilise both manual techniques and MS-Project software).
- A time analysis for the project including ES, LS, Floats etc. Comment on these results.
- A Gantt chart for the proposed project using Microsoft Project (or other software).
- A resource analysis for the project and resource histograms. Consider areas where resources may be critical and comment on an approach to levelling the resources.
- A detailed description on strategies to make the best use of resources.
- A cost estimate for the project including all relevant costs (site establishment, materials, labour, overheads etc.)
- A cash flow analysis for the project and a cash flow diagram.
- Detail strategies to crash the network. Explain the advantages and disadvantages of this strategy?
- A risk management plan for program delays, resource availability etc.
- A report on the profitability of the proposed project. Based on the total cost of the project (land, house, duties, etc.), calculate the break-even point for selling the residence. What profit margin are you looking for? Is the selling price feasible considering current residential property sales in the region?

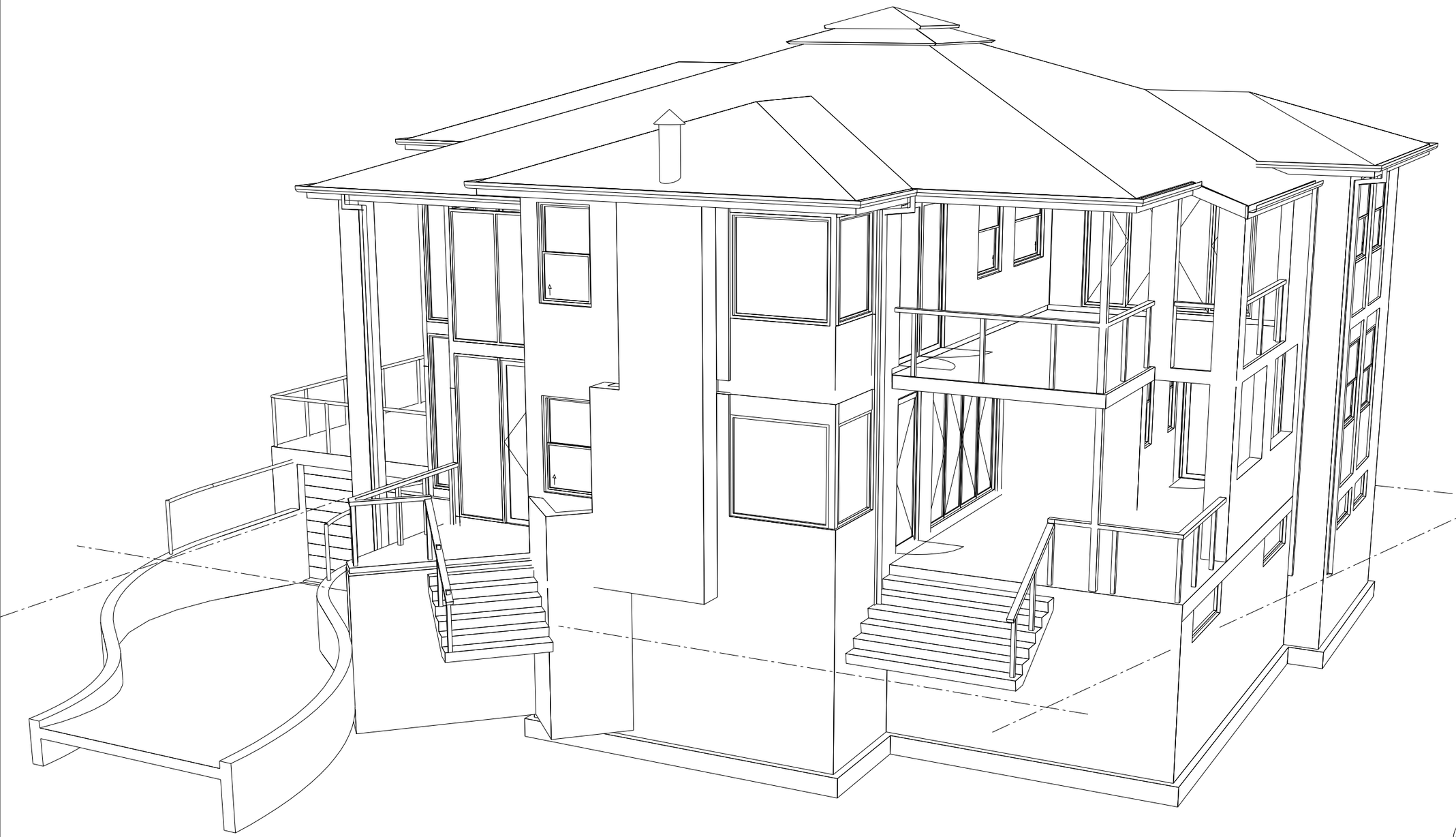
The assignment will be in the form of a **professional report** to the project manager.

**What is this assignment worth?**

Since this is the only assignment for this course it is worth **100%**. **Note**: This is an **individual assignment** – **plagiarism will not be tolerated**. Understandably you will consult each other for estimates on quantities, durations etc.

**Assumptions?**

Since you have received architectural plans only and not detailed structural, building services, equipment, civil plans etc. you may need to make some assumptions about quantities of materials etc. Also, you may not have an idea on material, labour costs etc. You should undertake some research (e.g. Rawlingsons guide) to obtain approximate costs and specify activity durations to the best of your ability. You **will not be penalised** for not knowing exact costs and quantities; this is not the purpose of this assignment.



| | | |
|---|---|---|
| A | BA ISSUE | 20.12.05 |
| P4 | PRELIMINARY ISSUE | 19.12.05 |
| P3 | PRELIMINARY ISSUE | 13.12.05 |
| P2 | PRELIMINARY ISSUE | 05.12.05 |
| P1 | PRELIMINARY ISSUE | 24.11.05 |
| Issue | Revision | Date |

Project
McGRADE HOUSE

Location
41 RANKIN PDE, MAIN BEACH
QEENSLAND

Client
JOYCE & GERRY McGRADE

Title
PERSPECTIVE


Forgan Smith Architects (Qld.) Pty Ltd
28 Ashmore Road
Bundall, Qld
PO Box 5095
Gold Coast Mail Cents 4217
Queensland. Australia
Telephone (07) 5539 0199
Facsimile (07) 5539 0408
Email farchit@onthenet.com.au
A.C.N. 082 057 770


| | | | |
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| | | issue | A |

drawing
61 WD - A - 010


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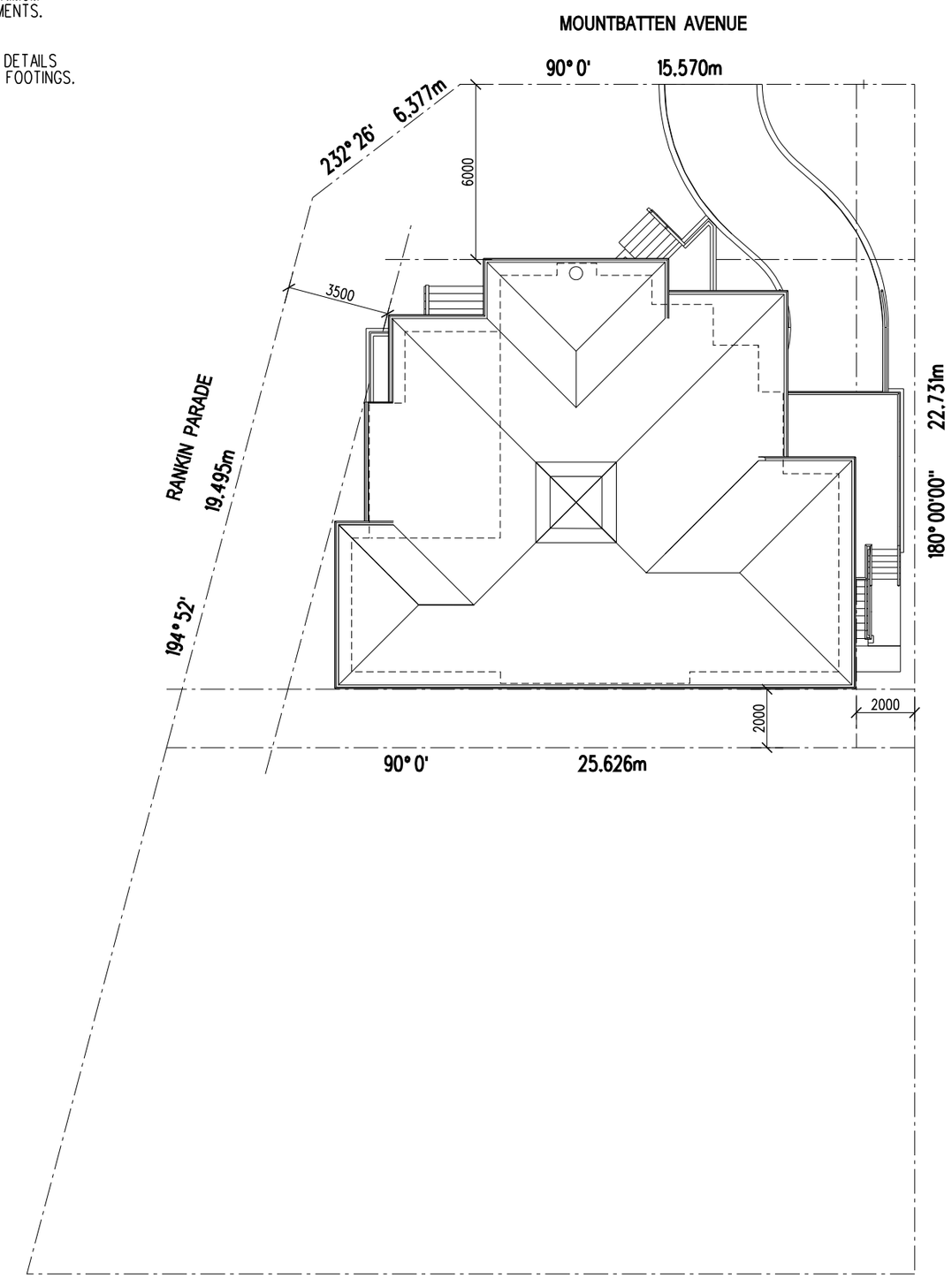
DRIVEWAY CROSSOVER TO LOCAL AUTHORITY REQUIREMENTS.

STORMWATER TO BE DISCHARGED TO STREET THROUGH MINIMUM 2 x 90 DIA. U.P.V.C. PIPES TO LOCAL AUTHORITY REQUIREMENTS.

PROVIDE SEWER GRADE PIPES TO STRUCTURAL ENGINEERS' DETAILS WHERE STORMWATER PIPES GO UNDER SLAB OR THROUGH FOOTINGS.

DOWNPIPES TO BE MAXIMUM 12m APART.

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| A | BA ISSUE | 20.12.05 |
| P4 | PRELIMINARY ISSUE | 19.12.05 |
| P3 | PRELIMINARY ISSUE | 13.12.05 |
| P2 | PRELIMINARY ISSUE | 05.12.05 |
| P1 | PRELIMINARY ISSUE | 24.11.05 |
| Issue | Revision | Date |

Project
McGRADE HOUSE

Location
41 RANKIN PDE, MAIN BEACH
QEENSLAND

Client
JOYCE & GERRY McGRADE

Title
SITE PLAN


Forgan Smith Architects (Qld.) Pty Ltd
28 Ashmore Road
Bundall. Qld
PO Box 5095
Gold Coast Mail Cente 4217
Queensland. Australia
Telephone (07) 5539 0199
Facsimile (07) 5539 0408
Email ferchit@ontheret.com.au
A.C.N. 082 057 770


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01 WD-06

02 WD-06

90° 0' 15.570m

232° 26' 6.377m

18800

600 4500 7390 6310

SPOON DRAIN

BCJ

DP

R 3190

R 6350

DP

1300 600 450

LIFT

1510 190

GRATED DRAIN

BCJ

2115 1600 300 4000 410

990

2790

TURNTABLE

R 2000

490

2200 245 900 965

GRATED DRAIN BCJ

820

01 02 03 04 05 06 07 08 09

4683

4200

3115

1932 7068 4590 400

648 1610 win 2790 1610 win 410 940 1210 win 290 1210 win 940

2490 410 190 2900 190

4310 190

2310 2200

DP DP BCJ

BCJ

SPOON DRAIN

DP BCJ DP

5100 1930 1810 win 2750 2000 1810 win 1290

2200

13990

19.495m

07 WD-08

06 WD-08

194° 52'

BASEMENT

1000 3000 5390 4200 400

13990

22.731m

180° 00'00"

ENCLOSED AREA = 211.4 SQ M

90° 0' 25.626m

5100 6490 5100 2110

18800

05 WD-08

04 WD-08

03 WD-07

N

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| A | BA ISSUE | 20.12.05 |
| P4 | PRELIMINARY ISSUE | 19.12.05 |
| P3 | PRELIMINARY ISSUE | 13.12.05 |
| P2 | PRELIMINARY ISSUE | 05.12.05 |
| P1 | PRELIMINARY ISSUE | 24.11.05 |

| Issue | Revision | Date |
|---|---|---|

Project
McGRADE HOUSE

Location
41 RANKIN PDE, MAIN BEACH
QEENSLAND

Client
JOYCE & GERRY McGRADE

Title
BASEMENT PLAN


Forgan Smith Architects (Qld.) Pty Ltd
28 Ashmore Road
Bundall, Qld
PO Box 5095
Gold Coast Mail Cente 4217
Queensland. Australia
Telephone (07) 5539 0199
Facsimile (07) 5539 0408
Email farchit@onthenet.com.au
A.C.N. 092 057 770


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| | | issue | A |

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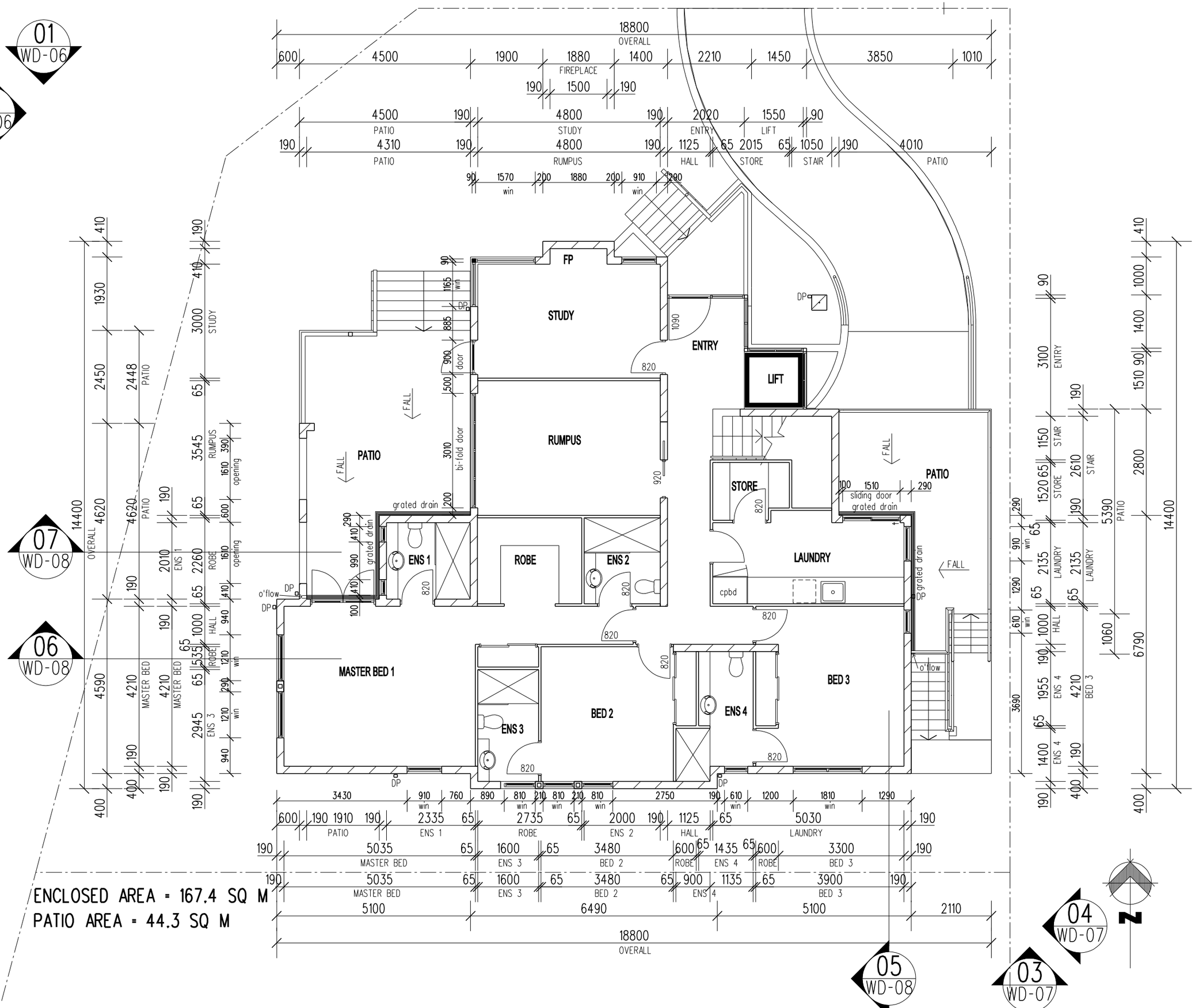


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| A | BA ISSUE | 20.12.05 |
| P4 | PRELIMINARY ISSUE | 19.12.05 |
| P3 | PRELIMINARY ISSUE | 13.12.05 |
| P2 | PRELIMINARY ISSUE | 05.12.05 |
| P1 | PRELIMINARY ISSUE | 24.11.05 |

| Issue | Revision | Date |
|---|---|---|

Project
**McGRADE HOUSE**

Location
**41 RANKIN PDE, MAIN BEACH QEENSLAND**

Client
**JOYCE & GERRY McGRADE**

Title
**GROUND FLOOR PLAN**


**Forgan Smith Architects (Qld.) Pty Ltd**
28 Ashmore Road
Bundall. Qld
PO Box 5086
Gold Coast Mail Cente 4217
Queensland. Australia
Telephone (07) 5539 0199
Facsimile (07) 5539 0408
Email farchi@onthenet.com.au
A.C.N. 082 057 770


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drawing
**61 WD-A-003**


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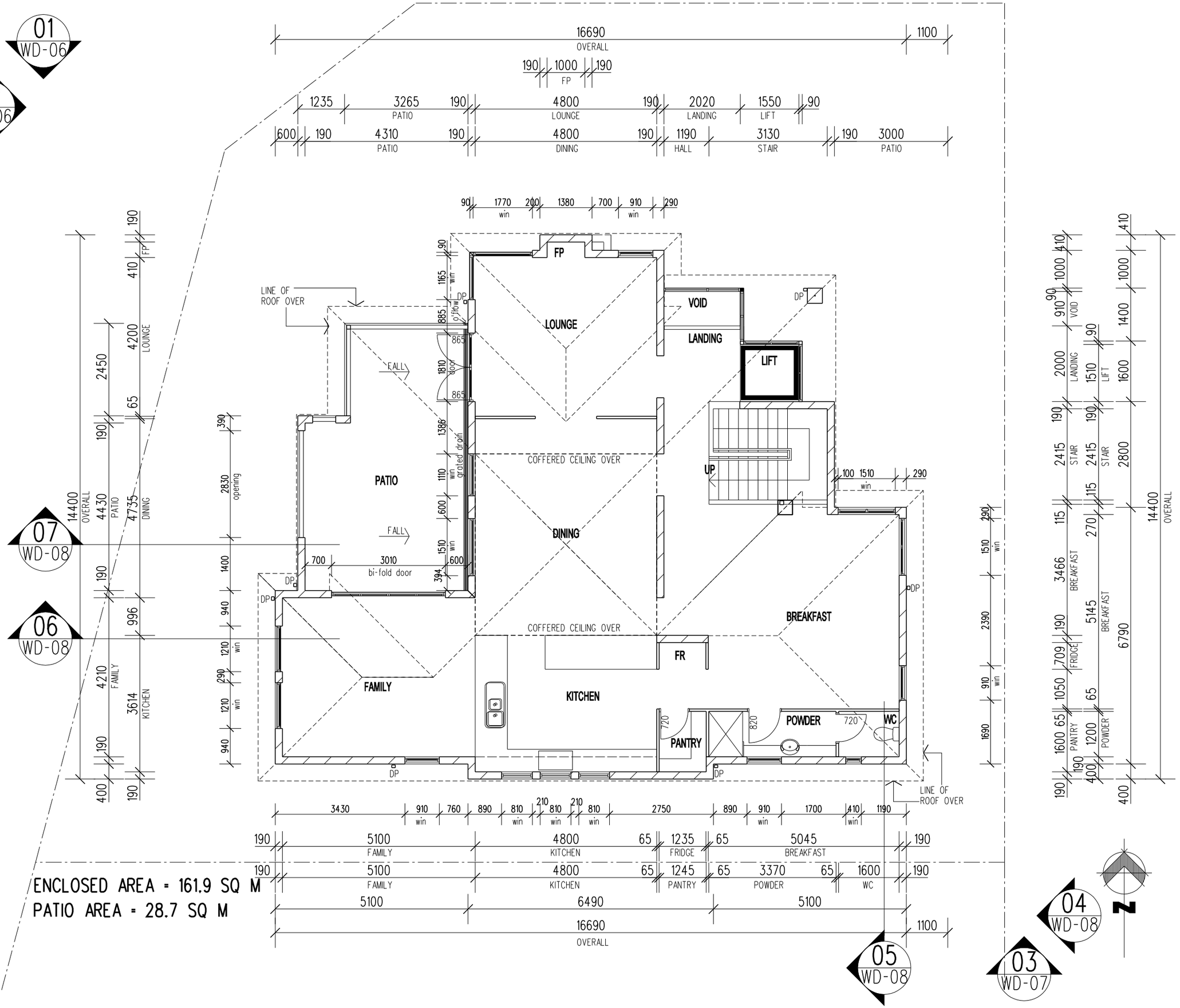


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| P3 | PRELIMINARY ISSUE | 13.12.05 |
| P2 | PRELIMINARY ISSUE | 05.12.05 |
| P1 | PRELIMINARY ISSUE | 24.11.05 |
| Issue | Revision | Date |

Project
McGRADE HOUSE

Location
41 RANKIN PDE, MAIN BEACH
QEENSLAND

Client
JOYCE & GERRY McGRADE

Title
FIRST FLOOR PLAN


Forgan Smith Architects (Qld.) Pty Ltd
28 Ashmore Road Bundall, Qld
PO Box 5096 Gold Coast Mail Cente 4217
Queensland, Australia
Telephone (07) 5539 0199
Facsimile (07) 5539 0408
Email farchit@ozemail.com.au
A.C.N. 082 057 770


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| | drawing 61 WD - A - 004 |


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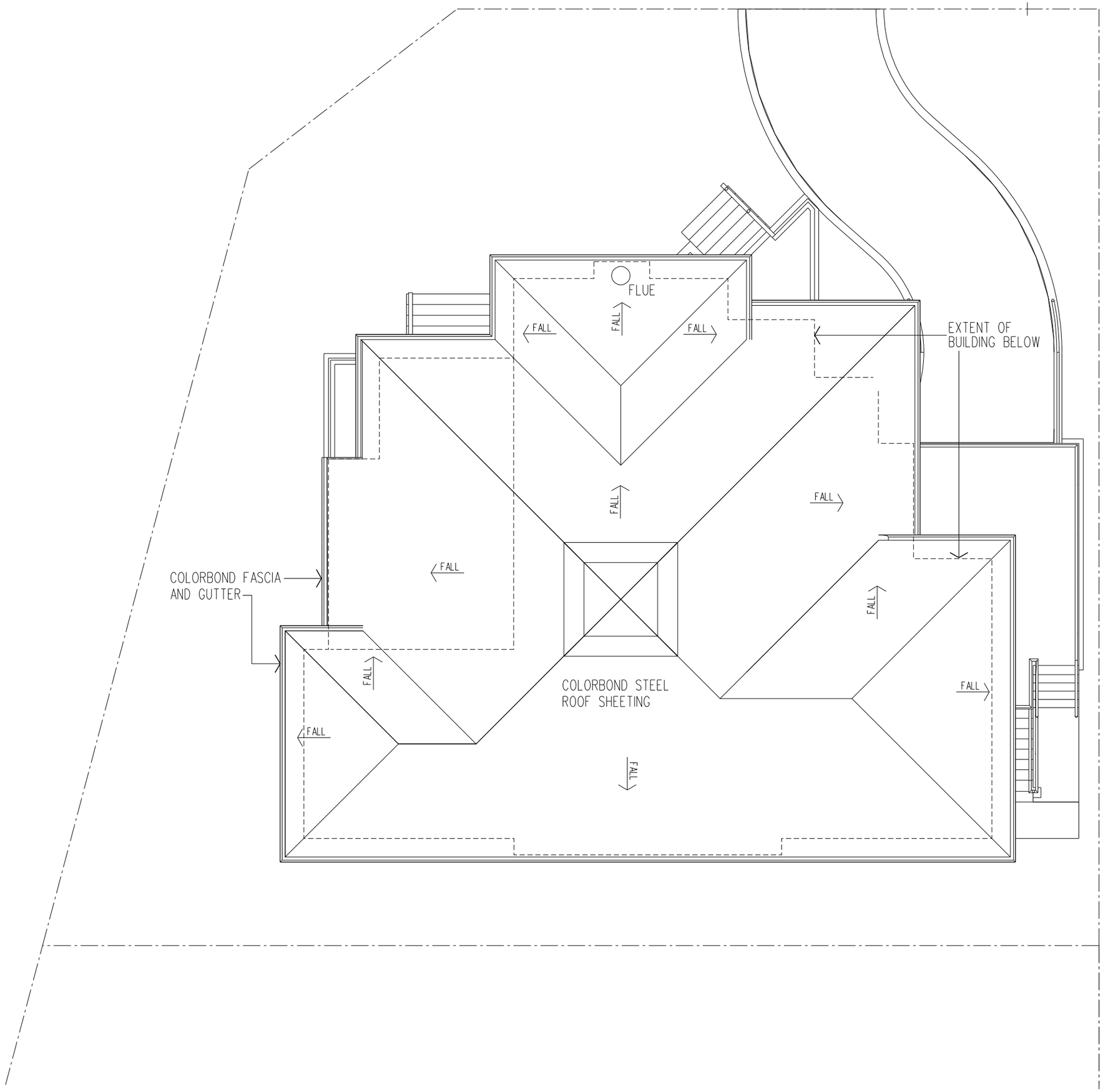
20° ROOF PITCH

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| P2 | PRELIMINARY ISSUE | 05.12.05 |
| P1 | PRELIMINARY ISSUE | 24.11.05 |

| Issue | Revision | Date |
|---|---|---|

Project
McGRADE HOUSE

Location
41 RANKIN PDE, MAIN BEACH
QEENSLAND

Client
JOYCE & GERRY McGRADE

Title
ROOF PLAN


Forgan Smith Architects
(Qld.) Pty Ltd
28 Ashmore Road
Bundall. Qld
PO Box 5026
Gold Coast Mail Centre 4217
Queensland. Australia
Telephone (07) 5539 0199
Facsimile (07) 5539 0406
Email fsarchit@ozemail.com.au
A.C.N. 082 057 770


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drawing 61 WD - A - 005


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01 ELEVATION

02 ELEVATION

| Issue | Revision | Date |
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| P4 | PRELIMINARY ISSUE | 19.12.05 |
| P3 | PRELIMINARY ISSUE | 13.12.05 |
| P2 | PRELIMINARY ISSUE | 05.12.05 |
| P1 | PRELIMINARY ISSUE | 24.11.05 |

Project
**McGRADE HOUSE**

Location
**41 RANKIN PDE, MAIN BEACH QEENSLAND**

Client
**JOYCE & GERRY McGRADE**

Title
**ELEVATIONS**

**Forgan Smith Architects (Qld.) Pty Ltd**
28 Ashmore Road
Bundall. Qld
PO Box 5095
Gold Coast Mail Cents 4217
Queensland. Australia
Telephone (07) 5539 0199
Facsimile (07) 5539 0408
Email farchit@onthenet.com.au
A.C.N. 092 057 770

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| issue | A |

drawing
61 WD - A - 006

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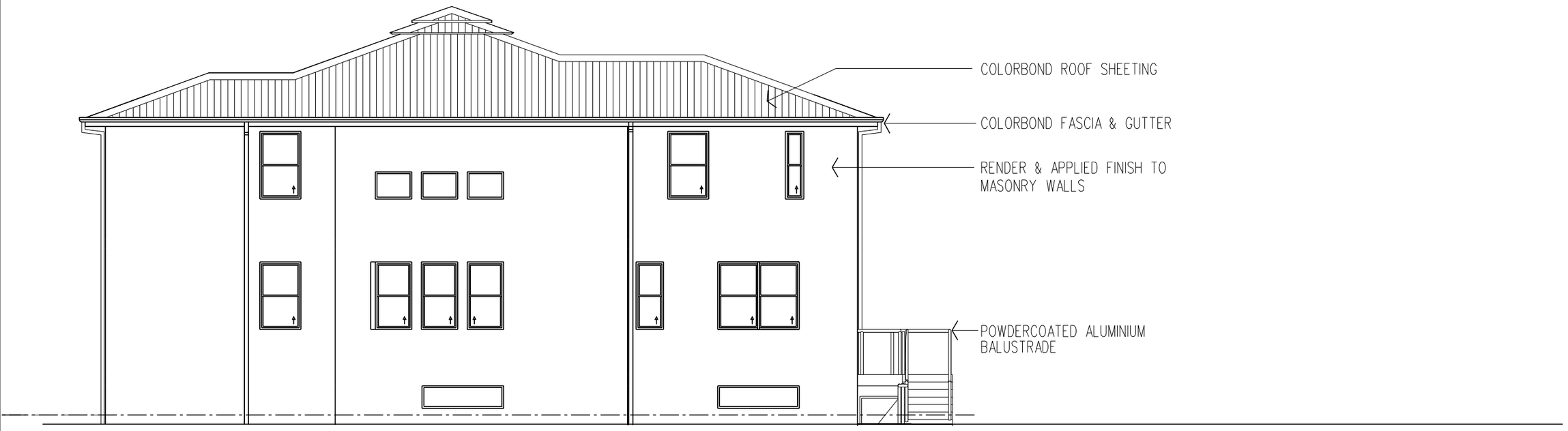


03 ELEVATION




04 ELEVATION

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| P2 | PRELIMINARY ISSUE | 05.12.05 |
| P1 | PRELIMINARY ISSUE | 24.11.05 |

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|---|---|---|

Project
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QEENSLAND

Client
JOYCE & GERRY McGRADE

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ELEVATIONS

Forgan Smith Architects (Qld.) Pty Ltd
28 Ashmore Road
Bundall. Qld
PO Box 5095
Gold Coast Mail Cente 4217
Queensland. Australia
Telephone (07) 5539 0199
Facsimile (07) 5539 0408
Email farchit@onthenet.com.au
A.C.N. 092 057 770

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| | | issue | A |

drawing
61 WD - A - 007

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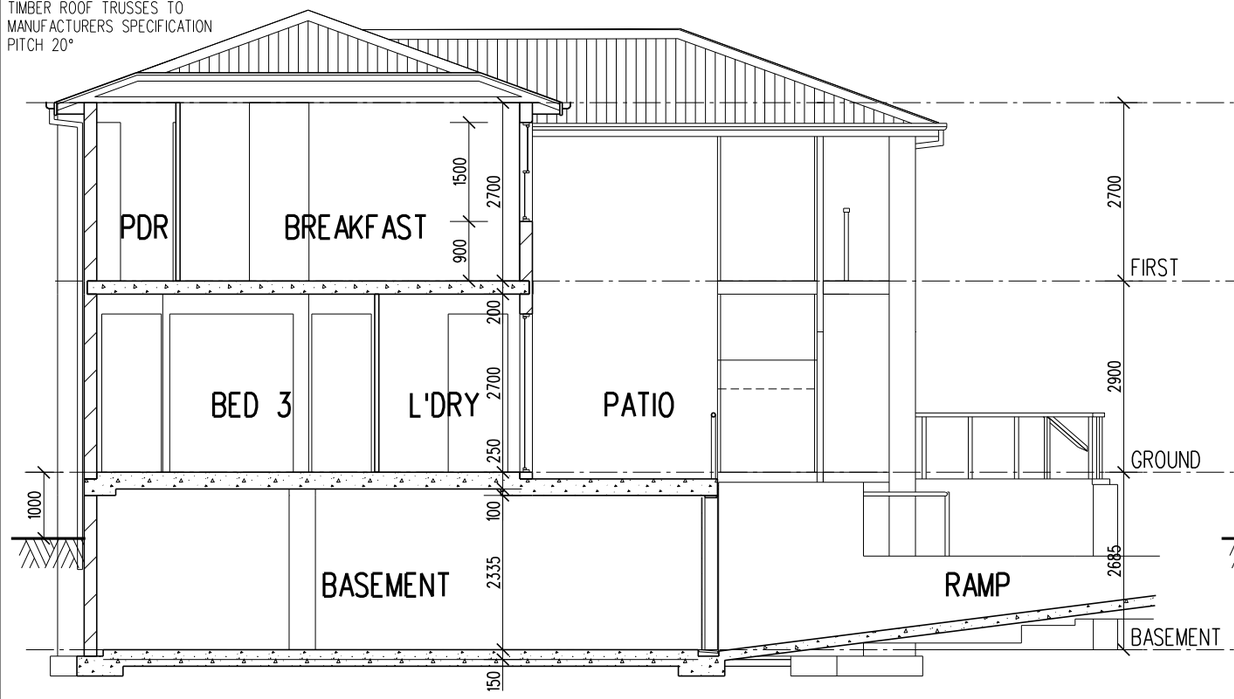
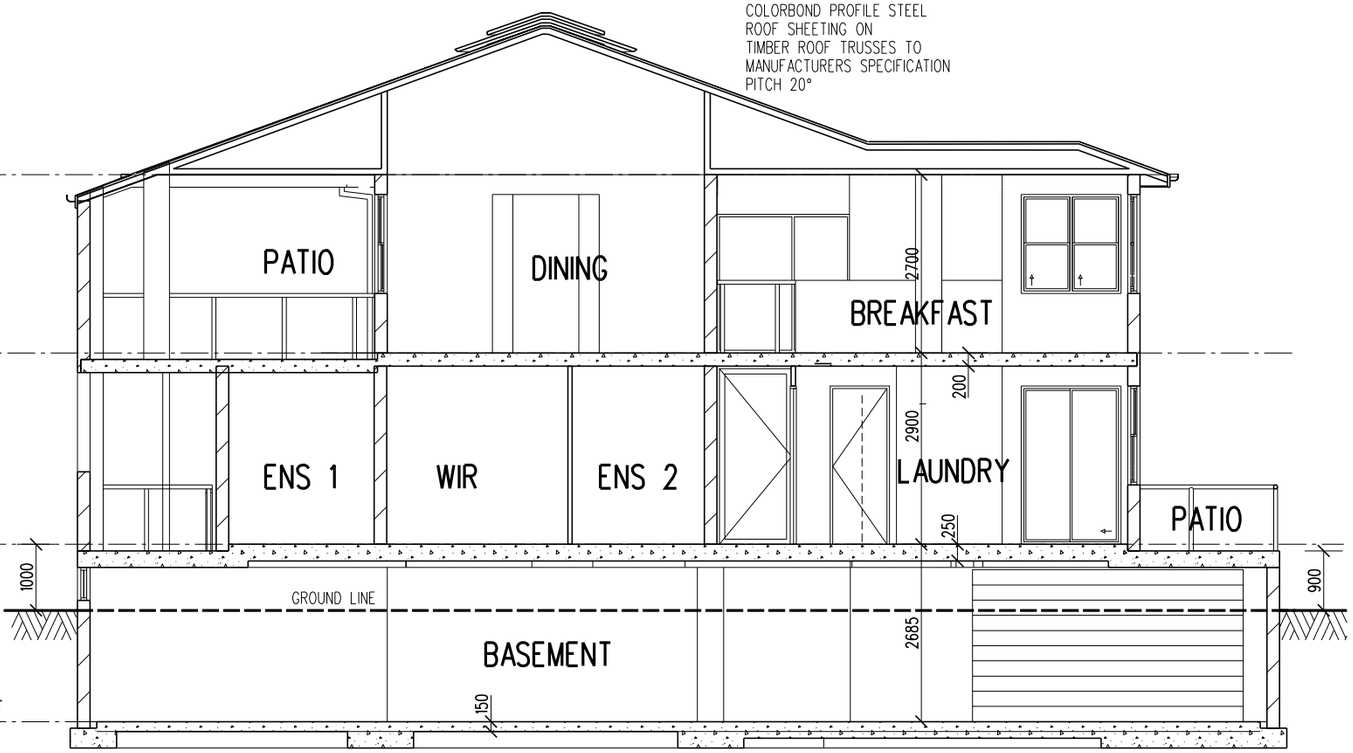
COLORBOND PROFILE STEEL
ROOF SHEETING ON
TIMBER ROOF TRUSSES TO
MANUFACTURERS SPECIFICATION
PITCH 20°

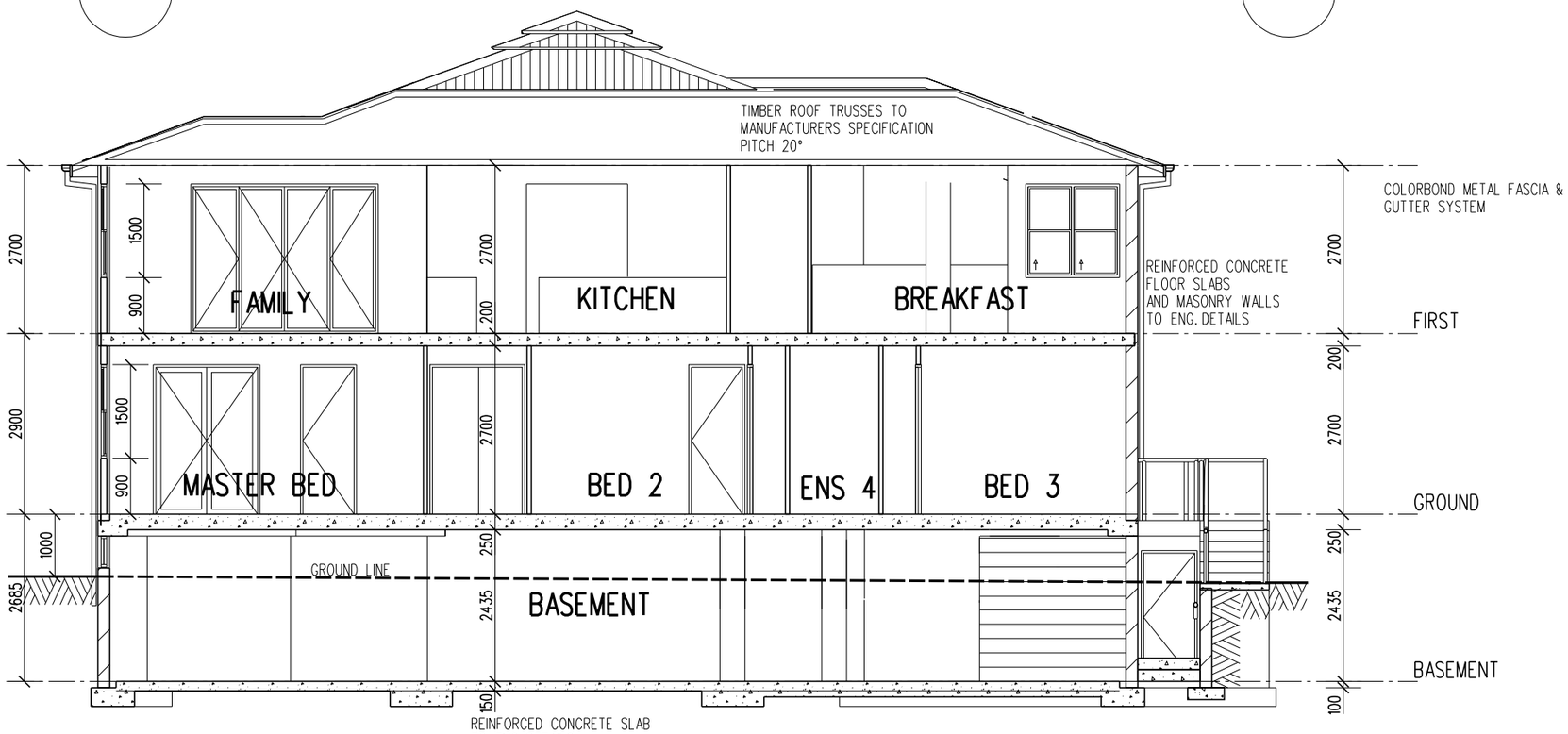



## 05 SECTION

COLORBOND PROFILE STEEL
ROOF SHEETING ON
TIMBER ROOF TRUSSES TO
MANUFACTURERS SPECIFICATION
PITCH 20°




## 07 SECTION




REINFORCED CONCRETE SLAB
TO ENG. DETAILS
ON 200 um W/P MEMBRANE ON
CONSOLIDATED SAND BED
TERMITE PROTECTION TO A.S. 3660

## 06 SECTION

REINFORCED CONCRETE SLAB
TO ENG. DETAILS
ON 200 um W/P MEMBRANE ON
CONSOLIDATED SAND BED
TERMITE PROTECTION TO A.S. 3660

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| P4 | PRELIMINARY ISSUE | 19.12.05 |
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| P2 | PRELIMINARY ISSUE | 05.12.05 |
| P1 | PRELIMINARY ISSUE | 24.11.05 |
| Issue | Revision | Date |

Project
**McGRADE HOUSE**

Location
**41 RANKIN PDE, MAIN BEACH**
**QEENSLAND**

Client
**JOYCE & GERRY McGRADE**

Title
**SECTIONS**


**Forgan Smith Architects (Qld.) Pty Ltd**
28 Ashmore Road
Bundall. Qld
PO Box 5095
Gold Coast Mail Cente 4217
Queensland. Australia
Telephone (07) 5539 0199
Facsimile (07) 5539 0408
Email farchit@onthenet.com.au
A.C.N. 092 057 770


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drawing
**61 WD - A - 008**


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# 7056ENG

Resource Planning and Management

# Multi-disciplined Assignment

Dr Rodney Stewart

# Proposal for
# Steel Reinforcement Plant

# Mesh and Cage Manufacturing
# Bar Processing

Annual Tonnage Throughput

| | |
|---|---|
| Mesh: | 40,000 tonnes |
| Bar: | 20,000 tonnes |

**Major Assignment – Multi-disciplined Engineering Project**

7056ENG Resource Planning and Management

Semester 2 – 2006

*Convenor*: Dr Rodney Stewart

*Due Date*: Friday Week 13 (27th October 2006)

**What is the Scenario?**

You have decided to design and build a small manufacturing facility for developing reinforcing steel products for the Queensland construction market (only two products: Reinforcing Steel bars (rib-wire) and Mesh). Before you begin the detailed design process you decide to undertake a preliminary design of the factory and manufacturing process as well as estimate the cost and time required to design and build the facility. Also, you would like to estimate the demand for the product and the envisaged production rates of the steel manufacturing facility to determine whether the project is feasible (i.e. consider a Return of Capital ratio). In a preliminary meeting with your project team, you decide that you need to complete the following tasks:

1. Complete a basic preliminary design of the factory (size, layout, crane requirements etc.).
2. Complete a preliminary design of the manufacturing process for reinforcing steel bars and mesh (i.e. schematics of the process and required machinery – see attached).
3. Consider quality assurance and testing facility requirements in the factory.
4. Consider what factory control facilities will be required.
5. Specify the layout of the manufacturing processes in the factory (see attached).
6. Investigate the specifications of required machinery and their approximate costs (see attached).
7. Investigate lead times for delivery of machinery and their source locations.
8. Investigate assembly/connection requirements for different machinery to develop the required steel manufacturing processes.
9. Investigate design and construction/process assembly durations and resource (i.e. engineers, labour etc.) requirements to develop the facility and the manufacturing process within it.
10. Investigate the sequence for designing and building the steel manufacturing facility (both external and internal).
11. Compile an estimate for the design and construction of the steel manufacturing facility (Note: it is not expected that you will go into detail for the civil and structural elements of the facility).
12. Consider the projects total cost to design and build.
13. Consider the demand for the products and envisaged production rates for the facility (see attached sheet for estimated production rates).
14. Consider annual operating costs for the facility based on production rates and staffing.
15. Consider profitability and returns from the facility based on estimated sales and operating costs.
16. Estimate the yearly Return on Capital (ROC) of the venture as a percentage.

Civil and structural elements should be considered for the planning and estimation for the steel manufacturing facility but detailed costing and scheduling is not required. However, you should be able to detail the basic elements of the structure such as footings, slab, frame, girts, purlins, sheeting etc. and their order of construction. Detailed below is an example of a simple factory layout.

**What should the assignment include?**

- Complete a basic preliminary design of the factory (size, layout, crane requirements etc.)
- Complete a preliminary design of the manufacturing process for reinforcing steel bars and mesh (i.e. schematics of the process and required machinery).
- Layout of the manufacturing process within the factory (see example attached).
- An itemised list of the tasks required for constructing the building and its internal manufacturing processes (see attached list).
- A work breakdown structure (WBS) for the proposed project.
- A detailed estimate of the resources required for each activity (Labour, machinery, materials, supervision etc.). Allocate costs to each activity in the WBS.
- A PDM diagram for the project (utilise both manual techniques and Microsoft Project software).
- A time analysis for the project including Critical Path, ES, LS, etc. Comment on these results.
- A Gantt chart for the proposed project using Primavera or Microsoft Project.
- A resource analysis for the project and resource histograms. Consider areas where resources may be critical and comment on an approach to levelling the resources.
- A detailed description on strategies to make the best use of resources.
- A cost estimate for the project including all relevant costs (site establishment, materials, labour, overheads, machinery etc.)
- Detail strategies to crash the network. Explain the advantages and disadvantages of this strategy?
- A cash flow analysis for the project and a cash flow diagram.
- A risk management plan for program delays, resource availability etc.
- A report on the profitability of the proposed project. Based on the total cost of the project, estimated demand for the product and the envisaged production rates of the steel manufacturing facility, determine whether the project is feasible (i.e. consider a Return of Capital ratio).

The assignment will be in the form of a **professional report** to the project manager.

**What is this assignment worth?**

Since this is the only piece of assessment for this course it is **worth 100%** - thus it is important to put in the effort and get it right. **Note**: This is an **individual assignment** – **plagiarism will not be tolerated**. Understandably you will consult each other for estimates on costs, quantities, durations, machinery requirements, production rates, sales data etc.

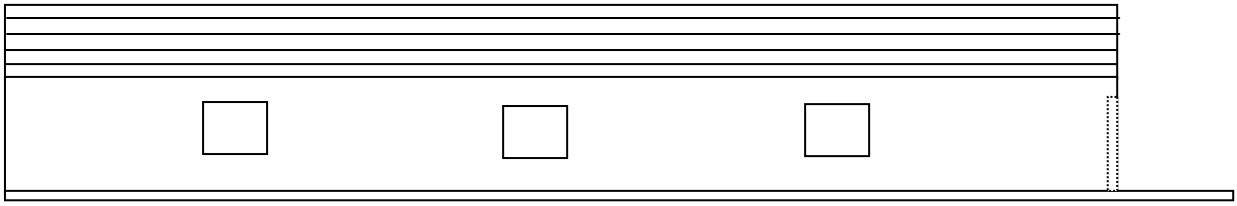
**Assumptions?**

Since you have received only minimal details about the factory you will need to make some assumptions about quantities of materials, machinery, resources, production etc. Also, you

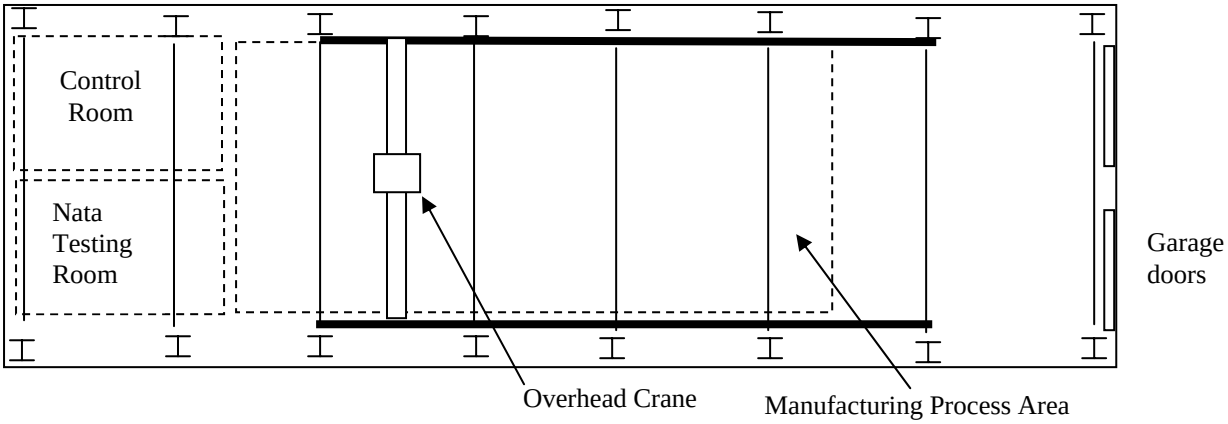
may not have an idea on material, labour costs etc. You should undertake some research (e.g. Rawlinson's guide) to obtain approximate costs and specify activity durations to the best of your ability. You **will not be penalised** for not knowing exact costs and quantities; this is not the purpose of this assignment.

See attached for a detailed manufacturing layout.

## Example Layout



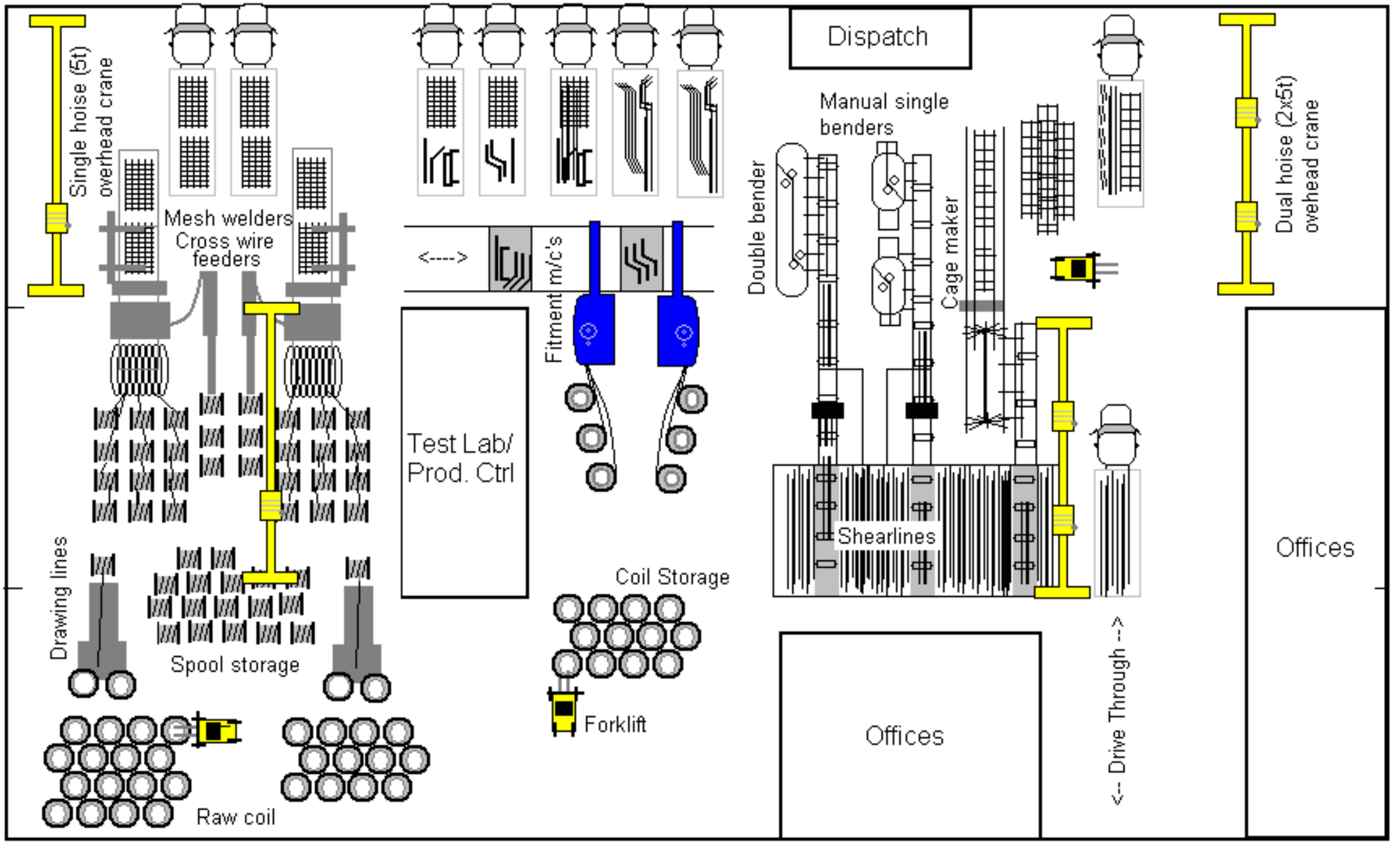
Elevation View



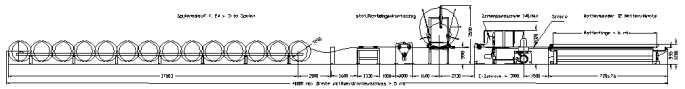

Plan View

**Some helpful web sites**

http://www.steel-n.com/esales/general/us/catalog/
http://www.nisshin-steel.co.jp/nisshin-steel/english/profile/s_make.htm
http://www.jfe-21st-cf.or.jp/index2.html


Single hoise (5t) overhead crane
Mesh welders
Cross wire feeders
Drawing lines
Spool storage
Raw coil
<---->
Fitment m/c's
Test Lab/ Prod. Ctrl
Coil Storage
Forklift
Dispatch
Manual single benders
Double bender
Cage maker
Shearlines
Offices
Offices
Dual hoise (2x5t) ovehead crane
<-- Drive Through -->

**Mesh Production**

| Item | QTY | Description | Typical Example |
|---|---|---|---|
| **Drawing Line Machine**<br><br>≈AUD 600,000 each*<br><br>*All prices are approximate and ex works. | 2 off | Cold Rolling Line (Teurema)<br><br>LG range of cold rolling lines for production of smooth or ribbed wire, for reinforcing and/or industrial mesh.<br><br>Constructed in modular form and totally enclosed, the lines feature vertical pay-off, mechanical descaler, lubricator, 2 cold rolling cassettes in line, vertical or horizontal multi-speed capstan, stress reliever (capstan driven), all installed on a common base frame. Horizontal and vertical spoolers are available with fully automatic operation, loading/unloading, strapping and handling of fixed or collapsible spool. | |
| **Automatic Welding Machine & Acces. (No auto crosswire)**<br>≈AUD 2M -2,500,000 each<br>(Depends on # of spool sets, sophistication of payoffs, degree of automation) | 2 off | **Automatic Welder**<br><br>The Automatic Welding Machines consists of series of line wire payoffs leading into a buffer looper. The line wires are pulled towards the welding head where the cross wires are positioned. A continuous feed of mesh is produced at which point after a nominated point is sheared to length. Usually accompanied by a 'stacker and turner' the every second piece of mesh is rotated and stacked to reduce stacking height. Automatic tying options are available. |  <br><br>For detail, refer to enlarged diagram attached. |
| **Cross Wire Feeder (attached to Welding Machine)**<br><br>≈AUD 320,000 each<br>(3 spool option instead of std 2, allows more flexibility and less downtime during change over) | 2 off | **Cross Wire Feeder (MBE)**<br><br>The Automatic Cross Wire Feeder is the accompanying machine to the Automatic Welding Machine, supplying a continuous feed of cut to length cross wires. | |

**Barshop Production**

| Item | QTY | Description | Typical Example |
|---|---|---|---|
| **Shearline**<br><br>≈AUD 164,000 each<br><br>(May prefer larger/ different model) | 2 off | **Mini Shearline/ Shearline 300 (Stema)**<br><br>Stationary reinforcing steel shearline. Modular concept for individual adaptation consisting of: In-feed conveyor, material storage rack, Simplex shear, measuring table with length stop and material kick-off, collecting pockets. Control for input of length and piece number.<br><br>High capacity, minimum floor space, one operator.<br>Flexible, meets customers' individual needs.<br>Control for all functions.<br>High performance hydraulic shear.<br>Automatic work-cycle. | |
| **Fitment Machine**<br><br>T12vx ≈AUD 330,000 (with some upgrade options. Base model ≈AUD 246,000)<br><br>T16II ≈AUD 520,000 (With upgrade options. Base model – no double bender etc.- ≈AUD 295,000)<br><br>Prices depend on # of reels, double bender, straighten benches, wire change magazines | 2 off | **Twinmatic 12 xv (Stema)**<br><br>Modern, efficient, versatile automatic stirrup bending machine designed to accommodate twin wires up to 10 mm Ø and single wire up to 12 mm Ø from hot-rolled and cold-drawn reinforcing steel in coils, spooled as well as unspooled.<br><br>**Twinmaster 16 II**<br><br>A new generation of automatic double wire stirrup bending machines for closed and perfect stirrups!<br><br>The Twinmaster 16 II represents state-of-the-art design and technology in straightening and bending hot rolled concrete reinforcing steel from coil, from 6 to 16 mm Ø.<br><br>The introduction of our revolutionary, tried and tested Anti-Stress Unit, means that poor quality material can also be processed trouble-free, and is fully integrated as standard equipment in the Twinmaster 16 II. | <br> |

| | | | |
|---|---|---|---|
| **Double Ended Bender**<br><br>≈AUD 240,000 each (Base model ≈AUD 205,000) | 1 off | **Permatic (Stema)**<br><br>Automatic bending line, one mobile and one stationary bending machine, clamp devices on both bending units, roller conveyor automatically adjustable in height, Siemens control, wide range of bending tools for +/- bending (accessories), four bending speeds. | |
| **Single Bender**<br><br>≈AUD 32,800 each (Base model for 'Special 60' i.e. Bends up to 60mm bars) | 2 off | **Special (Stema)**<br><br>Special Rebar Bending machines<br><br>Robust series for construction sites and rebar shops. Proven under extreme conditions. Easy electro-mechanic pin control. Forged bending plate, extra strong bending mechanism.<br><br>High-performance production machine, four adjustable pin hole rails, two bending speeds, supplied with complete set of bending tools. | |
| **Cage Maker**<br><br>≈AUD 280,000 each | 1 off | **Cage Maker (Schnell)**<br><br>A typical cage maker like this Schnell version shown can produced round cages 24m in length with diameters from 200mm to 1000mm. Some models available can produce dimeters up to 2000mm. | |

**Associated Facilities**

| Item | Cost Estimate |
|---|---|
| Laboratory facilities | ≈AUD 100,000 |
| Computers and software | ≈AUD 250,000 |
| Overhead gantry cranes<br>(30m span, single hoist for mesh with special lifting frame, double hoist for lifting bar, 5t carrying capacity. Factor in electrical busbar $16000/ 150m of track) | ≈AUD 50,000 each<br>(Min 4off required) |
| Factory (building) | ≈AUD 450,000 |
| Office (building) | ≈AUD 250,000 |
| Forklifts | ≈AUD 20-100,000 each<br>(Min 2off required for inside the factory, 1 large required to unload multiple coils from trucks) |